

## EDITORIAL

Towards the end of last year, one of my colleagues who was on leave in the United States sent back a cutting from the New York Times (8 August 1995) containing an article by Sandra Blakeslee entitled "Hopes for predicting earthquakes once so bright, are growing dim". The article was based on the views of a number of U.S. seismologists and geophysicists and describes how the science of earthquake prediction has fallen on hard times with some experts viewing earthquakes as a classic example of a chaotic system. Many U.S. seismologists are now reported to think that earthquakes are inherently unpredictable. They say that the search for ways to warn people days, hours, or minutes before an earthquake appears to be futile.

Currently, a third of the US\$100 million now spent on earthquake research and reducing hazards in the U.S. is spent on ways to construct safer buildings, bridges and highways. The rest is spent on basic research on understanding earthquakes and looking for ways to predict them. If earthquakes cannot be predicted, it is not surprising that some U.S. scientists think that much more of the money should be spent on reducing the hazards.

Whatever the outcome, the article reports that earthquake prediction has undergone a reversal of fortune from the belief of many scientists during the 1960s through to the mid-1980s that it was possible. Two scientific models drove this optimism. One, called dilatancy theory, is similar to what happens when people at a beach step on wet sand and the sand dries out around their feet. It was thought that the same phenomena would occur in earthquake faults before their failure, as stressed rocks deformed in a characteristic way and released water that could be detected. A second related idea, called the seismic gap hypothesis, says that earthquakes tend to repeat along known fault zones. After an earthquake, stress is released over time - perhaps several hundred years - strain reaccumulates and the fault is destined to break again in a more or less characteristic pattern.

The likelihood of earthquakes reoccurring along several segments of the San Andreas fault have been predicted using this latter model. Instruments were set up along one segment of the fault near Parkfield, about halfway between San Francisco and Los Angeles, where the seismic gap hypothesis predicted another earthquake should occur. The instruments are designed to find precursors, like subtle motions in the earth's crust, so that people can be warned shortly before an earthquake strikes. Unfortunately, the predictions have not been going as planned for the Parkfield earthquake is overdue, having been predicted to occur before 1992! Also, the most recent damaging earthquakes in North America and Japan - Loma Prieta, Northridge and Kobe - struck without any precursory signals.

More importantly, there seems to have been a shift in thinking about the dynamics of earthquakes. The idea that big stresses build up along fault zones and then have to be released in a characteristic manner is no longer considered to make as much sense as it once did. Since actual measurements deep in the ground indicate that stresses within faults are actually very weak, the mystery is why earthquakes occur at all with such small stresses. Apparently, clues to this mystery are now being found in the new science of chaos and complexity with earthquakes being a classic example of a chaotic system.

In this view, the earth's crust is prone to constant shifting, particularly along fault lines. Tiny earthquakes are occurring all the time. In major seismic regions of the world, thousands of earthquakes may be detected each year, though most are not felt. However, for reasons not understood, some of these small earthquakes do not stop. Local rock conditions or other geologic factors allow a magnitude one earthquake to expand into a magnitude two earthquake involving a larger region. Less commonly, a magnitude two earthquake develops into or sets off a magnitude three earthquake, and so on. According to this view, a big earthquake can be thought of as a small one that has run away. The problem in earthquake prediction lies in being able to predict in sufficient detail just which of the small earthquakes will become large.

However, not all scientists share this pessimism and a number of geophysicists have recently proposed an earthquake model that might help to determine which earthquakes could become large. This involves measuring the slow, steady slip that occurs along fault before they undergo high speed slipping that gives rise to an earthquake. One of the problems is how to detect slow slippage (so slow that it doesn't generate seismic waves) over sufficiently large areas.

According to the article, the recent large earthquakes in California and Japan have had the effect of bringing the debate about earthquake prediction to public notice rather than letting it remain in more academic circles. Now some people are calling for the Government to stop spending money on earthquake research and put it all into reducing earthquake hazards. As a seismologist at the United States Geological Survey says, that would be foolish as faults could interact in complex ways and not understanding them could be more costly in the long run.

Nevertheless, there are suggestions that more could be spent on engineering research as there is serious under-investment in our knowledge of how buildings work in earthquakes, how the ground moves and how buildings react. The recent large earthquakes have shown that tall structures in our cities are likely to suffer severe damage. After the Northridge earthquake for instance, it was found that about 100 steel-framed buildings were damaged, and they had been considered to be one of the better type of earthquake resistant structure. As the Californian Seismic Safety Commission says in its report on the Northridge earthquake: "Despite our codes and world-renowned expertise, too many of our buildings and other structures remain vulnerable to earthquake damage. There are significant weaknesses in the way we exercise land use planning laws and design and construct buildings and lifelines". One solution offered is for a moratorium on building any new structures over six stories high in the Los Angeles area until engineers know how to build tall structures that can withstand moderate and severe shaking!

If nothing else, it looks as though the debate about earthquake prediction and how best to spend funds to improve seismic safety will go on for some time yet, not only in the United States but also in New Zealand, Japan and other countries in the highly seismic regions of the world.

# LESSONS FOR NEW ZEALAND LIFELINES ORGANISATIONS FROM THE 17 JANUARY 1995 GREAT HANSHIN EARTHQUAKE

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## ABSTRACT

This report outlines the observations and findings with regard to lifelines and other infrastructural items from each of the various New Zealand post-earthquake visits to Kobe subsequent to the NZNSEE reconnaissance team visit. The preliminary assessments on lifelines aspects made in the NZNSEE reconnaissance team report are developed further. Lessons and recommendations for New Zealand are presented.

In addition to lifelines aspects, observations are also made on the political decision-making process, subsequent economic trends and temporary housing and emergency management issues.

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## 1 INTRODUCTION

### 1.1 Background

At 5.46 am on 17 January 1995 the Hyogo-Ken Nanbu (Great Hanshin) earthquake struck the Kansai region of Japan. More than 5,500 people were killed and 26,800 seriously injured. Approximately 300,000 people were made homeless, with 234,000 in Kobe City itself.

Kobe is Japan's sixth largest city, with a population of 1.5 million people. The Hanshin district is the second most important industrial area in Japan after the Tokyo - Yokohama area.

This earthquake is clearly of interest to New Zealand and is of particular relevance to Wellington due to geographical and geological similarities. Although of lesser magnitude than that portrayed for the Wellington Fault Event earthquake, the concentration of damage to a narrow but long strip is considered to represent a comparable effect. There are also parallels with other areas in New Zealand, as an earthquake of this scale was not anticipated in this part of Japan, despite the national context of high seismicity.

In addition to the severe damage suffered by many buildings, this earthquake caused major damage and disruption to lifelines on a much wider scale than other recent international events. Accordingly, this earthquake presented a unique opportunity for lifelines managers, engineers and researchers from New Zealand to learn key lessons experienced by their Japanese counterparts. Information has been keenly sought in relation to the likely extent of damage that the various lifelines in New Zealand could anticipate, the effectiveness of recent mitigation measures and issues associated with the response and recovery phases.

### 1.2 Scope of This Report

The commitment of New Zealand to learning and applying the lessons from the Great Hanshin earthquake has been clearly demonstrated by the people and groups who have visited Kobe in the months following the event.

These have included:

- The immediate post-earthquake reconnaissance mission by a 13-person party organised by the New Zealand National Society for Earthquake Engineering and headed by Professor R. Park, with David Spurr being responsible for compiling the material on lifelines [Park et al., 1995]. A subsequent follow-up visit was made in July by Ian Billings, a member of that team, looking at the recovery of the transportation networks [Billings, 1995].
- The study of the disaster response and recovery startup undertaken from 12 - 24 March 1995 by Neil Britton and Rachel Scott of the Wellington City Council Emergency Management Office [Britton and Scott, 1995].
- The study of reconstruction progress undertaken from 8 - 10 May 1995 by Ian McLean, the then chairman of the Earthquake Commission, and currently convenor of the Disaster Recovery Review [McLean, 1995].
- The visit in July 1995 by the New Zealand Gas Association Working Party, comprising Guenter Wabnitz (GasDirect),

Lee Findlay (Enerco Gas Auckland) and Phil Shields (Enerco Gas Palmerston North).

- Attendance at the sixth Joint U.S./Japan Lifelines Workshop held in Osaka in July 1995 by David Hopkins (Kingston Morrison Ltd), John Lumsden (Centre for Advanced Engineering) and John Norton (Hutt City Council) [Hopkins, 1995b].
- The New Zealand Lifelines Study Tour undertaken in August 1995 by members of the Wellington Earthquake Lifelines Group and Christchurch Engineering Lifelines Project.

In addition, visits have been made during this period by others representing individual organisations and associations.

This report draws together information relating to lifelines obtained by members of the New Zealand Lifelines Study Tour and the New Zealand representatives who attended the sixth Joint U.S./Japan Lifelines Workshop. Material from reports of the earlier visits is also drawn upon.

### 1.3 The Sixth Joint U.S./Japan Workshop on Earthquake Disaster Prevention for Lifelines Systems

This workshop was held in Osaka on 18 and 19 July 1995. David Hopkins, John Lumsden and John Norton from New Zealand were invited to participate, joining 52 Japanese and 12 United States delegates. Their attendance at this workshop provided a valuable forerunner to the Lifelines Study Tour undertaken in August.

Thirty-two presentations were made on the full range of issues from detail on physical mitigation to mathematical techniques for analysing lifeline system operations and interaction. Proceedings from the workshop are available; a summary of the papers has been given by Hopkins [1995].

Given the proximity to Kobe, post-workshop tours of the affected city enabled the opportunity to learn more of how the key lifeline organisations coped with the earthquake damage and managed their response and recovery phases.

The workshop was hosted by the Public Works Research Institute of Japan.

### 1.4 New Zealand Lifelines Study Tour

This week-long tour to Kobe was undertaken from 27 August to 1 September 1995. Arrangements for this visit were made through the Mayor's Office of Kobe City.

The following people from New Zealand participated in this tour:

- Peter Leslie, Divisional Manager Utility Services, Wellington Regional Council
- Councillor Ernie Gates, Wellington Regional Council
- Graeme Hughson, (formerly) Drainage Manager, Wellington City Council
- Dick Carter, Project Engineer, Port Wellington
- Mark Gordon, Roading Manager, Christchurch City Council
- Alan Watson, Manager Waste Management Unit, Christchurch City Council

- John Lamb, Project Manager, Christchurch Engineering Lifelines Project
- David Brunson, Project Manager, Wellington Earthquake Lifelines Group

### 1.5 Acknowledgements

There has been a considerable financial commitment toward the information contained in this report from a number of organisations. The major contributors include:

Earthquake Commission  
Wellington Regional Council  
Wellington City Council  
New Zealand Gas Association  
Wellington Earthquake Lifelines Group  
Christchurch Engineering Lifelines Project  
Centre for Advanced Engineering  
Hutt City Council

The considerable effort made by the contributors to this and previous reports on the Kobe earthquake, much of it invariably outside normal working hours, is also worthy of note. This commitment of time, money and effort by organisations and individuals alike is gratefully acknowledged, with the collective value being reflected in the following pages.

The generosity in terms of time and sharing of information shown by the Japanese in hosting the New Zealand groups and individuals must also be acknowledged. Particular mention should be made of the Mayor's Office of the City of Kobe and the Public Works Research Institute of Japan. The willing assistance provided by Mr Kiyoyuki Kanemitsu, Director of the International Department of the Mayor's Office, proved invaluable.

## 2 THE EARTHQUAKE

### 2.1 General

The earthquake was of 7.2 Richter magnitude with a depth of the source of the earthquake of 16 km. The epicentre was approximately 20 km to the southwest of the coastal area of Kobe, just off the northeast end of Awaji Island as indicated in the location plan of Figure 2.1.

The earthquake caused a narrow zone of intensive damage of 1.5 - 2 km width and length of nearly 30 km, parallel with the coast, as shown in Figure 2.2.

The layout of Kobe and Osaka Cities is shown in Figure 2.3 with the critical east-west transportation corridor being readily apparent. The locations of critical expressway failures are indicated in this figure.

The peak damage intensity has been assessed as 7 on the Japanese Meteorological Agency (JMA) scale or MM X-XI on the Modified Mercalli scale.

The total damage is estimated to be in the range NZ\$150 to 200 billion.

The earthquake occurred on a near-vertical fault running north-east from the northern tip of Awaji Island towards Kobe along the foot of Mount Rokko. The maximum fault movement at the surface on Awaji Island was approximately 0.5m vertically and

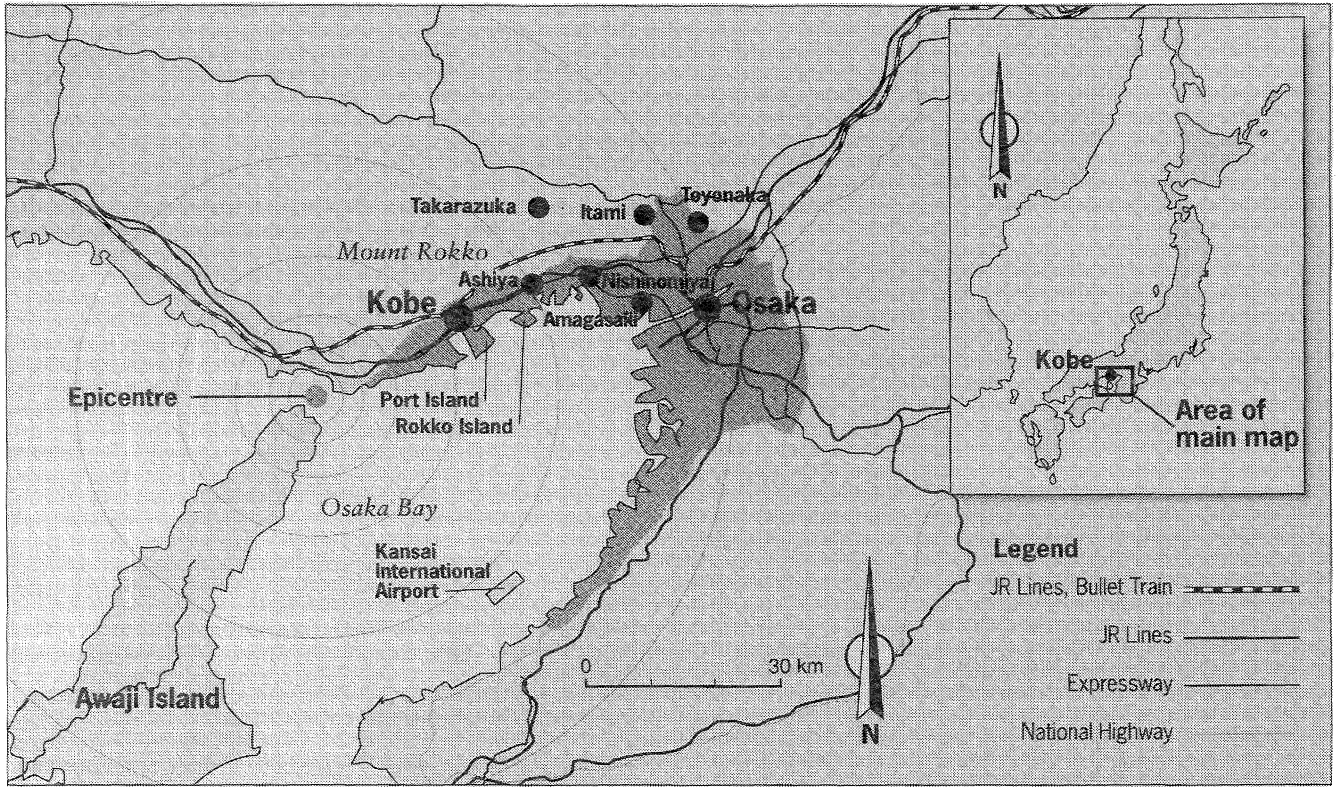


FIGURE 2.1 The Hanshin district showing the earthquake epicentre [Alexander Howden Group Ltd, 1995]

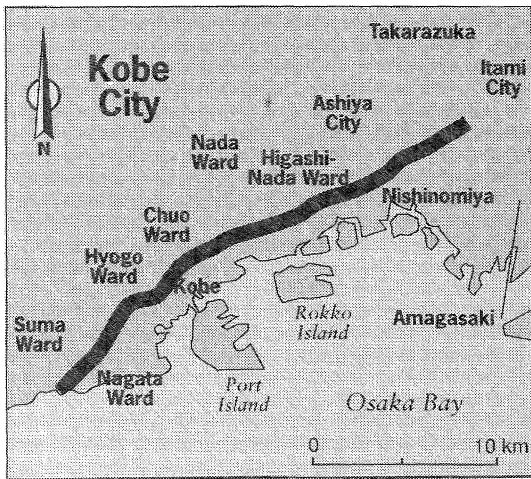


FIGURE 2.2 The approximate extent of MM9 and MM10 intensities [Alexander Howden Group Ltd, 1995]

1.2 m horizontally. While the fault runs through beneath Kobe City, no surface fault ruptures were found in the Kobe area due to the depth of relatively soft alluvial materials present at the foot of the Rokko mountains.

Liquefiable sands and sandy silts are present under all the reclamations and former beach areas. The total thickness of reclamation fill is up to 15 m.

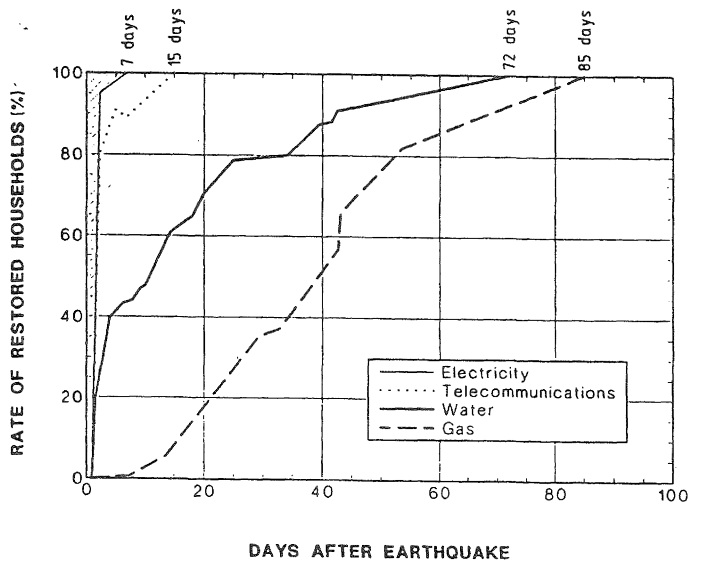


FIGURE 2.4 Restoration curves for lifelines after the Kobe earthquake [Takeda and Ueno, 1995]

The strongest recorded acceleration was 0.82g measured at the Kobe marine weather station. The period of strong shaking was approximately 20 seconds.

*Summary of the Effects on Individual Utility Services*

The overall response of key utility services in terms of the rate of service restoration is summarised in Figure 2.4. The number of days taken to achieve 100% service restoration takes account of the number of destroyed buildings.

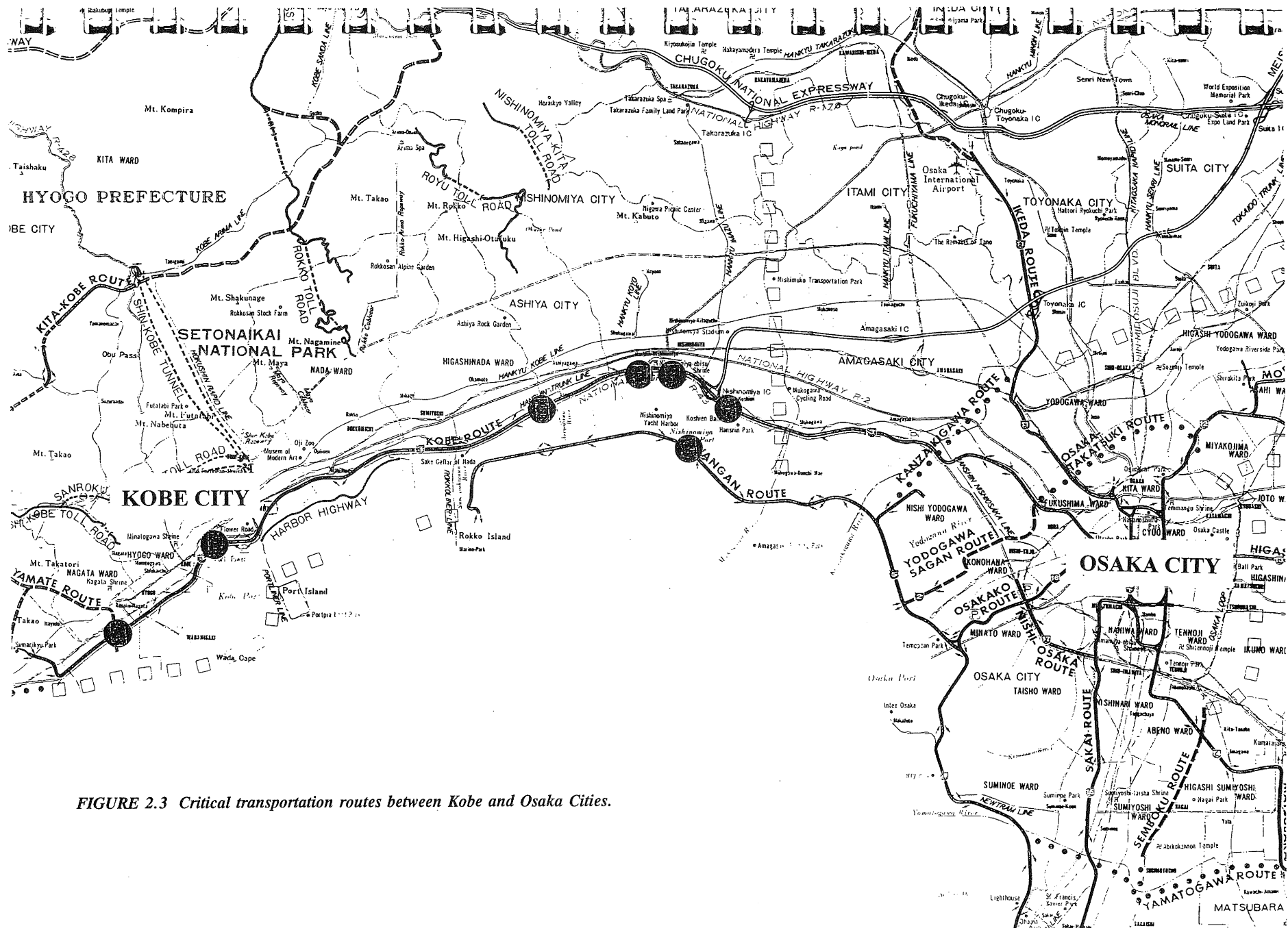


FIGURE 2.3 Critical transportation routes between Kobe and Osaka Cities.

### *Water Supply*

Even with the high levels of preparedness and mitigation undertaken by Kobe City Waterworks, the level of damage was considerable, with an estimated NZ\$500 million damage being sustained. This was the first time in Japan that there had been a complete water outage. It took 11 days to restore water to 50% of customers and 72 days to achieve 100% restoration.

### *Wastewater Services*

Widespread damage to Kobe's sewerage and stormwater drainage infrastructural assets was experienced, with an estimated damage cost of NZ\$670 million. The full extent of this damage will take more than a year to determine. The planned two year works programme for full recovery is reliant upon very high levels of funding support from the national government.

### *Transportation Networks*

The loss of elevated sections of the Hanshin Expressways and the railway structures that were constructed prior to the early 1970's severely restricted transportation capability. The cost to repair the Hanshin Expressway and to upgrade to current earthquake standards is estimated at NZ\$7.6 billion.

While rail services were restored within 160 days, it will take nearly two years to renew damaged parts of the elevated expressway network, causing continuing disruption to local travel patterns and the economy.

### *Port Facilities*

The loss of virtually all of the port facilities has had a considerable adverse impact on the regional economy. Port reconstruction costs are estimated at NZ\$10 billion and all repairs are programmed to be completed 2 years after the earthquake.

Most of the working berths at the port were seriously affected by the earthquake and were forced to close until temporary or permanent repairs could be carried out. Large areas of reclamation suffered settlement, and rotation of the wharf face caisson structures caused severe damage to all of the container cranes in the port.

The port has moved with great rapidity to reconstruct its facilities. While some cargoes continue to be diverted through other ports, the trade through the Port of Kobe had recovered to 63% of its pre-earthquake volumes within 7 months of the earthquake.

### *Gas Supply*

The Osaka Gas Company supplies a total of 5.6 million customers in the greater Osaka region. After the earthquake, 860,000 customers in Kobe and neighbouring cities were without gas. It took the company almost three months to repair the damaged network and restore supply to those whose premises remained intact. The considerable amount of repair work required made up the largest part of the company's stated losses due to the earthquake of NZ\$3.2 billion.

### *Electrical Networks*

The power supply network in the Kobe area suffered significant damage, with 25% of the 11.7 million customers in the Osaka

region losing power. Approximately half of the transformer substations within the highest intensity zone were damaged. These had all been constructed prior to 1965.

While service was fully restored within a week of the earthquake, the estimated cost of rebuilding all necessary damaged facilities is NZ\$3.8 billion. Mitigation and preparedness measures previously implemented were considered to have been particularly effective. In addition to a system design featuring a high degree of redundancy and flexibility, participation in a nationwide mutual aid scheme brought significant assistance with personnel and materials.

### *Telecommunications Facilities*

In addition to the loss of 285,000 lines, network capacity limitations were experienced in the days following the earthquake.

The vulnerability of overhead lines was again highlighted. While underground cables sustained much less damage than overhead lines, the importance of having flexible connections at building interfaces was shown. This earthquake has also emphasised the considerable amount of time required to check the condition of underground ducts after a major earthquake. Mitigation work carried out following previous major earthquakes has focused on underground facilities, and the Kobe earthquake has demonstrated the value of this work.

## **3 WATER SUPPLIES**

### **3.1 Network Description**

Since its modern water supply system was introduced in 1900, the City of Kobe has relied upon the Yodogawa river system for about three quarters of the approximately 830,000 cubic metres of water consumed each day.

The water supplied from the Yodogawa river is the responsibility of the Hanshin Water Supply Authority (a Public Corporation set up by four cities including Kobe to be the bulk supplier). The water is supplied through two distribution tunnels.

Kobe obtains the remaining quarter from its own water sources and a small amount from a water supply project operated by the Hyogo Prefecture. In principle, the water distribution system is a gravity flow system. It has a stratified distribution system with four pressure zones and reservoirs at 119 locations.

The principal waterworks facilities are shown in Table 3.1. The network is shown in Figure 3.1 [Kobe City Waterworks Bureau, 1994].

### **3.2 Damage Assessment Report**

#### *Overview*

The total estimated damage to the water supply system is estimated at NZ\$500 million.

The main damage was to the distribution mains (between 50 mm diameter and 900 mm diameter) and the service mains (smaller than 75 mm diameter). As at 30 April 1995 over 14,000 leaks had been repaired under public roads and 58,000 leaks on private residential land.

# WATER SUPPLY SYSTEM

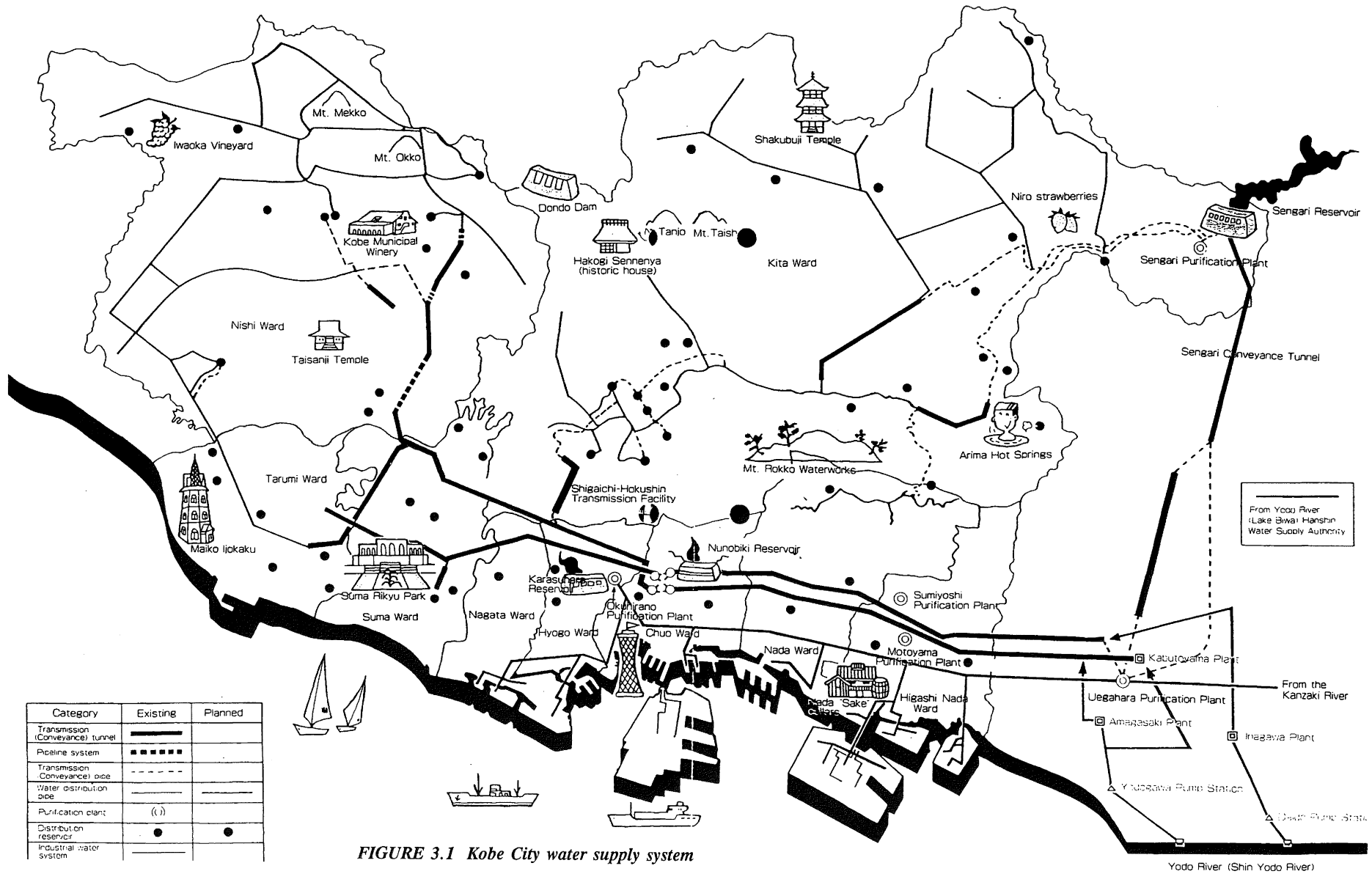


FIGURE 3.1 Kobe City water supply system

Table 3.1: Principal Waterworks Facilities (refer also to Figure 3.1)

No	Item	Urban Area (including Seishin)	Hokushin District	Rokkosanjo District	Total
1	Open Reservoirs/Dams	Nunohiki • Torihara	Sengari		
2	Transmission Tunnels	Old Tunnel	No. 1 Tunnel		
		New Tunnel	No. 2 Tunnel		
		(Tunnel Connecting the Urban Area with the Hokushin District)			
3	Service Reservoirs	82 locations 168 reservoirs	34 locations 63 reservoirs	3 locations 8 reservoirs	<b>119 locations</b> <b>240 reservoirs</b>
4	Pumping Stations No. of Pumps	29 locations 159 units	10 locations 45 units	5 locations 11 units	<b>44 locations</b> <b>215 units</b>
5	Purification Plants	4 locations Uegahara, Okuhirano, Motoyama, Sumiyoshi	2 locations Sengari Arima	1 location Rokkosan	<b>7 locations</b>
6	Length of Conveyance, Transmission, and Distribution Pipes (km)	Conveyance Pipes: 42 km Transmission Pipes: 259 km Distribution Pipes: 4,028 km			<b>4,329 km</b>

The numerous breaks led to the complete loss of water in many areas. The resulting no water or low pressure situation made finding leaks difficult.

There was relatively little damage to the main purification plants and reservoirs. This was due to their location on good ground conditions (i.e. away from the liquefaction and high intensity ground shaking areas) and robust design.

The other significant item of damage was the collapse of the sixth floor of the City of Kobe's No. 2 Office Building. This was the head office of the Waterworks Bureau and its loss had considerable implications for the restoration phase. Fortunately the Okuhirano Purification Plant, which is the main operational control centre for the water supply system, suffered minimal damage.

A full description of the damage supplied by the City of Kobe Water engineers [Kobe City Waterworks Bureau, 1995; Matsushita, 1995] is set out in the following sections.

#### Basic Facilities

- *Dams*

There are small cracks in two dam bodies.

- *Aqueduct*

Some collapses and cracks were seen in Sengari Aqueduct Tunnel.

- *Purification Plant*

The Uegahara Purification Plant is the most severely damaged of the seven purification plants in Kobe City. This damage occurred to the slow sand filter, rapid sedimentation basin, wash water tank and wastewater treatment facility. At the Motoyama Purification Plant there were some cracks in the wash water tanks and leaks in various plant pipelines.

- *Water Transmission Tunnels and Pipes*

No failures were evident in two water tunnels which convey water to Kobe City. However, there were some leaks in the pipelines to Jumonji and Konan service reservoirs. Some collapses of concrete structures were seen in Motoyama and Kumochi water pipeline tunnels.

- *Service Reservoirs*

At the Egeyama Service Reservoir cracks between the old structure and new structure resulted in all the stored water being lost. To date no failures have been evident at the remaining 118 service reservoir locations.

- *Other*

The buckling of the steel tower at the Okuhirano Control Centre, which is used for telemetry and telecontrol functions, did not affect operations.

#### Pipelines

Pipelines suffered the most severe damage from this earthquake. The number of distribution pipeline failures reached over 1600 as at the end of April. As Table 3.2 shows, the largest cause of failure is joint separation (64%). The rest are pipe breaks (21%) and pipe fitting failures (16%). Besides these pipe failures, Kobe engineers comment that there are many leaks which are still to be found by leakage survey teams.

Table 3.2 does not show damage by type of pipe or by type of ground. This information is still being assembled as part of a long term project.

The water pipelines to the artificial islands of Port Island and Rokko Island were severed. The damage to the bridges was a major barrier against the quick recovery of water service to these areas.

Table 3.2: Diameter and Types of Failure (Distribution Main)

Diameter (mm)	Length (m)	No. of Cases	Cases/Length (-/km)	Type of Failure		
				A	B	C
50	63,143	15	0.24	7	8	0
75	165,051	49	0.30	9	33	7
100	790,329	313	0.40	73	193	47
150	1,455,137	565	0.39	117	378	68
200	744,689	263	0.35	62	181	20
250	39,706	21	0.53	8	13	0
300	386,606	222	0.57	36	157	29
350	18,195	5	0.27	0	4	1
400	79,700	48	0.60	9	25	14
450	3,082	0	0.00	0	0	0
500	88,450	28	0.32	3	8	17
600	45,224	16	0.35	1	3	12
700	46,857	29	0.62	1	6	22
800	10,264	9	0.88	1	7	1
900	26,131	26	0.99	3	11	12
1000	498	1	2.01	0	0	1
<b>Total</b>	<b>3,963,062</b>	<b>1,610</b>	<b>mean 0.41</b>	<b>21%</b> <b>332</b>	<b>64%</b> <b>1,027</b>	<b>16%</b> <b>251</b>

Type of failure      A: Pipes (breakdown, etc.)      (April 1995)  
    B: Joints (pulled out, etc.)  
    C: Fittings (fire-hydrants, etc.)

### Wells

The effects of the Kobe earthquake on wells drilled into an aquifer was able to be studied from experience at the nearby Municipality of Akachi. Akachi's water supply is from an underground aquifer. 60 wells have been drilled 180 metres deep. There are 4 associated purification plants.

Although Akachi is just to the north west of the epicenter and closer to it than the majority of Kobe City, it is understood that Akachi is not founded on the same poorly compacted soils nor directly above the fault which moved. None of the wells or purification plants had any problem. Kobe City had one private well under the Municipal building and that continued to supply satisfactorily after the earthquake even though that was right in the zone of the greatest damage.

In Akachi, there was originally some concern in that the level of the groundwater rose by up to 5 metres but apparently this soon settled back to normal. There was also a deep spring which increased its flow by about three times but in August this was back to about 1.5 - 2 times the flow before the earthquake. The volume of water increased considerably for 10 hours after the earthquake.

In the Christchurch Engineering Lifelines project, a worldwide literature search failed to reveal any reports on the way in which water wells have performed under earthquake loadings and it is very reassuring to know of the Akachi experience.

Disruption to the supply of water from underground aquifers is most likely to occur as a result of differential movement between the wellheads and other structures rather than from damage to the wells themselves.

### Service Connections

Till the end of April, the number of service connection repairs reached 12,827 in roads and 58,408 in private property making a total of 71,235. Most were due to pipe breaks and joint separation following the collapse of houses and road deformation. This large number of failures was the main reason for the rapid water loss from the distribution pipelines.

### 3.3 Effectiveness of Mitigation and Preparedness Measures

#### Overall

The degree of preparedness and extent of mitigation measures was impressive. This is due to Japan as a country being very conscious of the need to be "disaster prepared". This is in part due to the relatively frequent occurrence of typhoons.

Each year a day is set aside for national disaster preparedness and all organisations visited had annual disaster preparedness exercises. Relatively frequent typhoons also provide an opportunity to test disaster plans, albeit on a much smaller scale than the Kobe earthquake.

In addition, high quality "earthquake proof" materials are used throughout the water works system. These include special earthquake proof pipe joints which typically allow about 60 mm elongation and 3° rotation. These measures reduced the damage and accordingly assisted the restoration.

Overall, Kobe's mitigation and preparedness measures are rated highly effective although there was still massive disruption to the water supply. This has to be expected with the best plans and mitigation measures. The success is really how quickly the water supply can be restored.

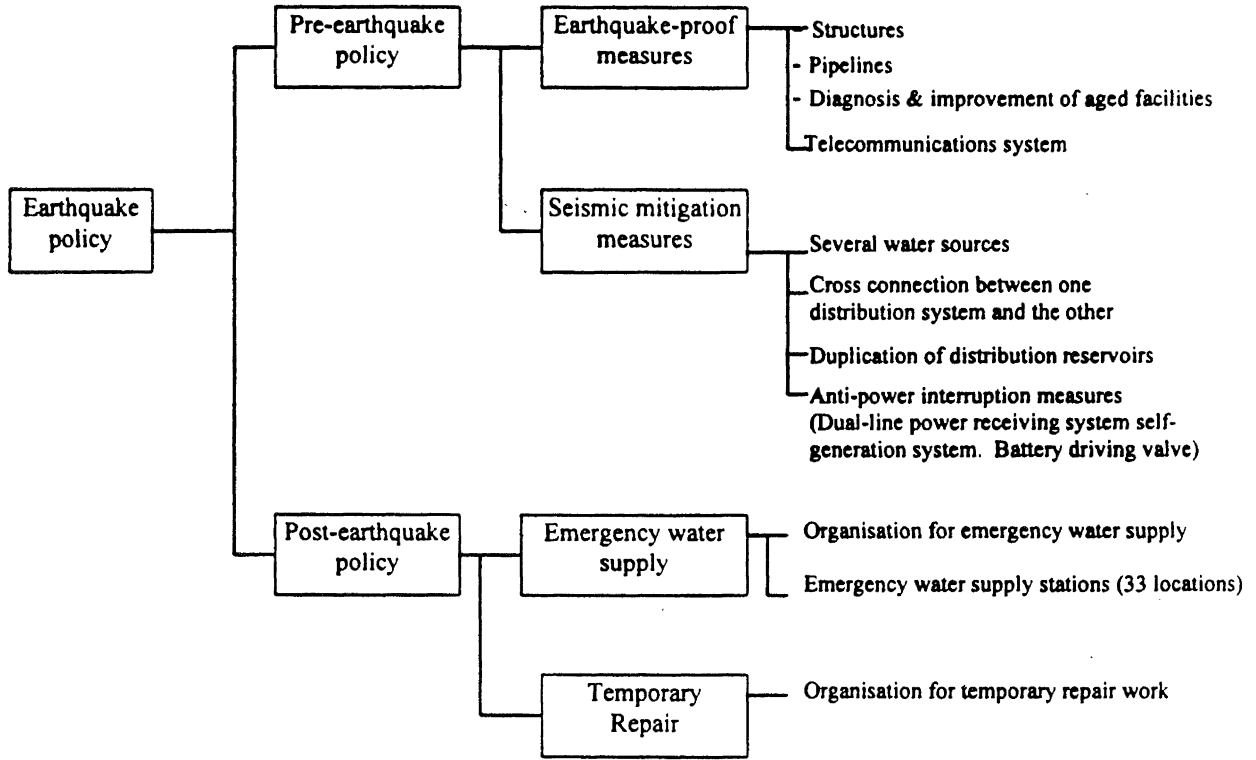


FIGURE 3.3 Earthquake Policy for Water Supply in Kobe City

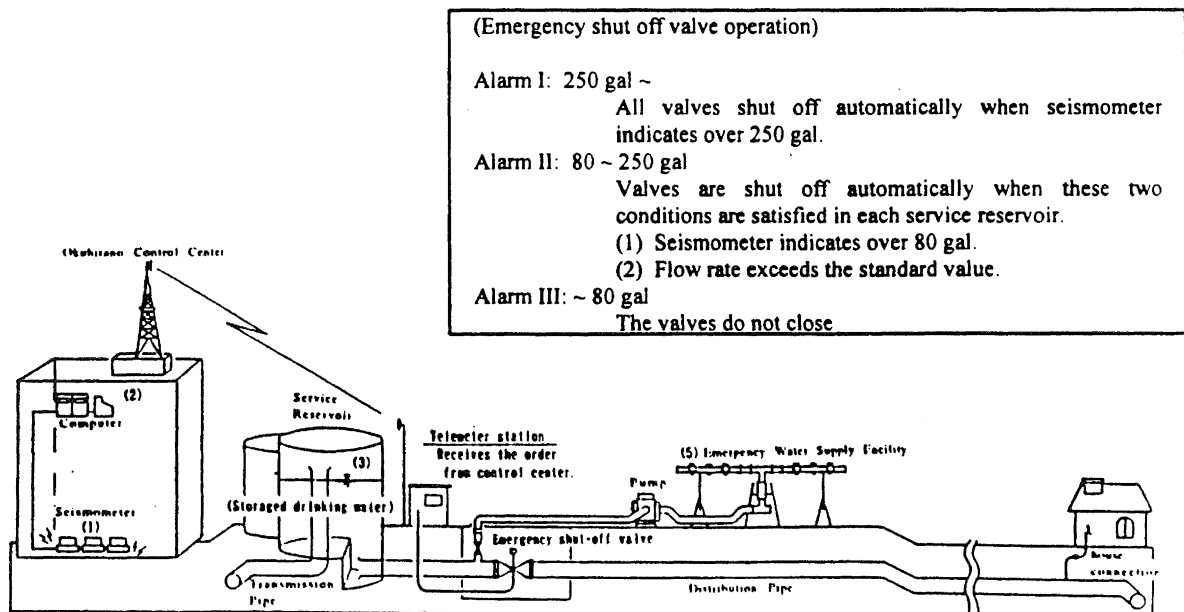


FIGURE 3.4 Emergency Shut-off Valve System

### **Kobe City Earthquake Policy**

Kobe City had a comprehensive Earthquake Policy in place at the time of the earthquake. This was outlined in the "little red book" which is given to all staff members. Unfortunately it is not available in English.

The policy applying to water supply is set out in Figure 3.3. As can be seen it is split into pre earthquake measures and post earthquake measures.

The pre earthquake measures are:

#### **(i) Emergency Shut Off Valve System**

The system is shown diagrammatically in Figure 3.4.

33 of the reservoir sites have effectively been designated emergency drinking water sites. At these sites 2 reservoirs are provided. Depending on the level of the earthquake and/or the level of outflow (see Figure 3.4), the valve on one reservoir is closed. The aim is that 3 litres/person/day for 7 days is stored for all the people who will be supplied with emergency drinking water from that particular reservoir.

The layout plan for the Emergency Shut-off Valve System is based on people not having to walk further than 2 kilometres for emergency water. The plan is similar to the system developed by the Wellington Earthquake Lifelines Group. However, the Wellington plan only goes as far as identifying locations where water is likely to be relatively soon after an earthquake if shut-off valves are installed.

The construction of Kobe's Emergency Shut-off Valve System commenced in 1985, and 21 valves had been installed at the time of the January 17 earthquake. All but two operated successfully.

#### **(ii) Replacement of Aged Pipes**

Recognising the importance of pipeline material type as part of its earthquake preparedness, Kobe has had a programme for the last 30 years of replacing all pipes with ductile iron. All new areas are also required to be laid with ductile iron. It was interesting that ductile iron pipes are even inserted inside existing cast iron pipes. At the time of the earthquake 86% of the pipe network was ductile iron, 3% steel and 11% is in what are considered to be unsatisfactory materials such as cast iron and PVC.

#### **(iii) Communication System**

Kobe City's communication system for operating the water supply network is a dedicated radio system which is independent of the telephone system. Although more expensive than utilising the telephone system, it was unaffected by the earthquake. This was invaluable during the response period particularly on the first morning when there were problems with the telephone system.

#### **(iv) Mutual Aid Agreements**

Kobe City had agreements with seven other cities to assist in an emergency situation such as after an earthquake. These apply to all functions including water supply. They were most helpful in the Kobe earthquake situation.

The post earthquake measures shown in Figure 3.3 for Emergency Water Supply Provision and temporary repairs are described in Section 3.4.

### **3.4 Response and Recovery Aspects**

#### **Overall**

Overall Kobe's response and recovery must be judged as a success. Initially all water was cut and it took 11 days to restore 50% of consumers and 72 days to restore 100% (refer to Figure 2.4). The restoration process is set out in Figure 3.5. The large amount of assistance from outside Kobe greatly contributed to the rapid response and recovery.

#### **Emergency Water Supply**

Kobe City Officials described the emergency water supply service as follows:

*"Because this was the first time water had been cut off in an entire city, supplying emergency water was an extremely time-consuming activity.*

*Although we were confident we could supply enough water for immediate needs, we were unable to make full use of our fleet of water trucks because of traffic congestion and other problems. This hindered the emergency supply project. In the evening of January 17 (the day of the earthquake), we started emergency water deliveries; mainly to 170 primary schools serving as evacuation centers. At the peak of this project, we were using 432 trucks on loan from 92 other cities. Water supply boats from the Marine Self-defense Force and the Maritime Safety Agency also helped with the project".*

It is interesting that water was provided both from the emergency reservoirs and after a few days by ship into the Port of Kobe.

#### **Fire Fighting**

The rapid loss of water through breaks in the mains meant that firemen faced a futile task. Attempts were made to pump water from the sea for fire fighting, but a lack of traffic control leading to vehicles running over hoses meant that this was not successful.

#### **Mutual Aid**

At the peak there were 734 workers from 43 cities repairing pipes under the streets and another 272 workers from 53 cities working on pipelines on private residential property. This support was arranged through the Japanese Waterworks Association and was invaluable in repairing the 71,000 leaks by the end of April.

#### **Recovery of Water Supply**

Kobe Water engineers highlighted the difficulties in fixing leaks because of low water pressure. As a result the somewhat laborious system set out in Figure 3.5 had to be rigorously used. This meant separating off the area associated with each distribution reservoir.

This process of trial water supply, identifying leaks and repair was repeated and the restoration rate gradually increased.

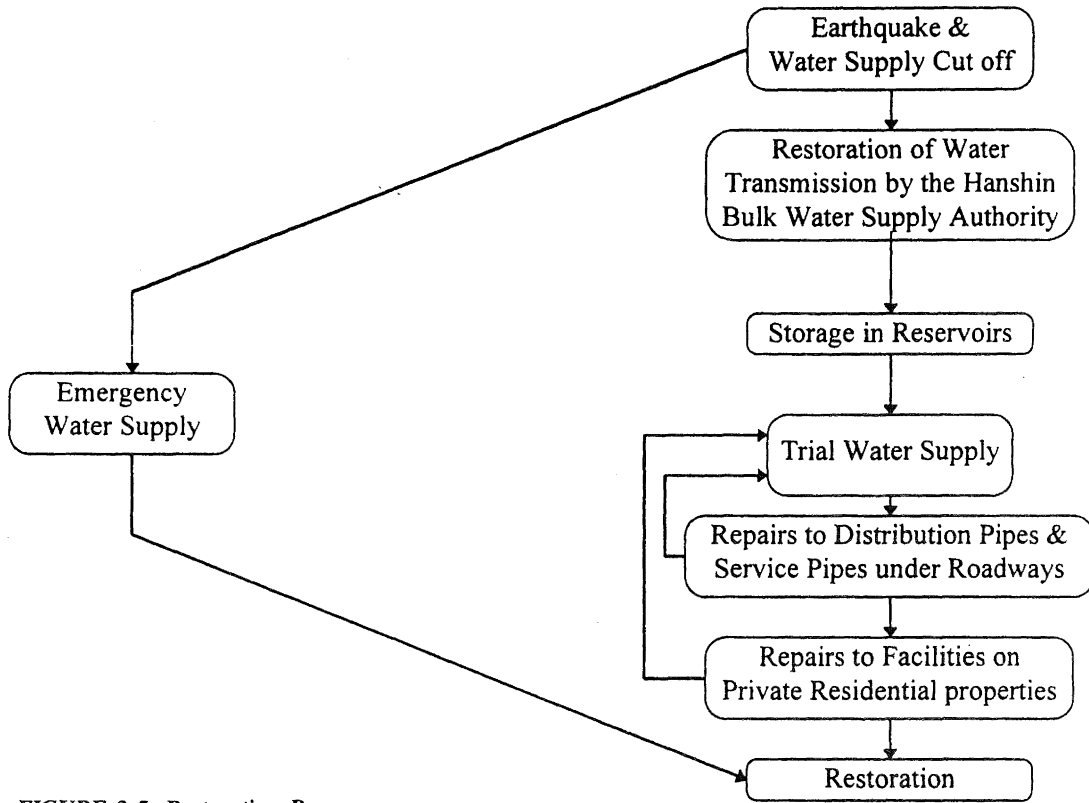


FIGURE 3.5 Restoration Process

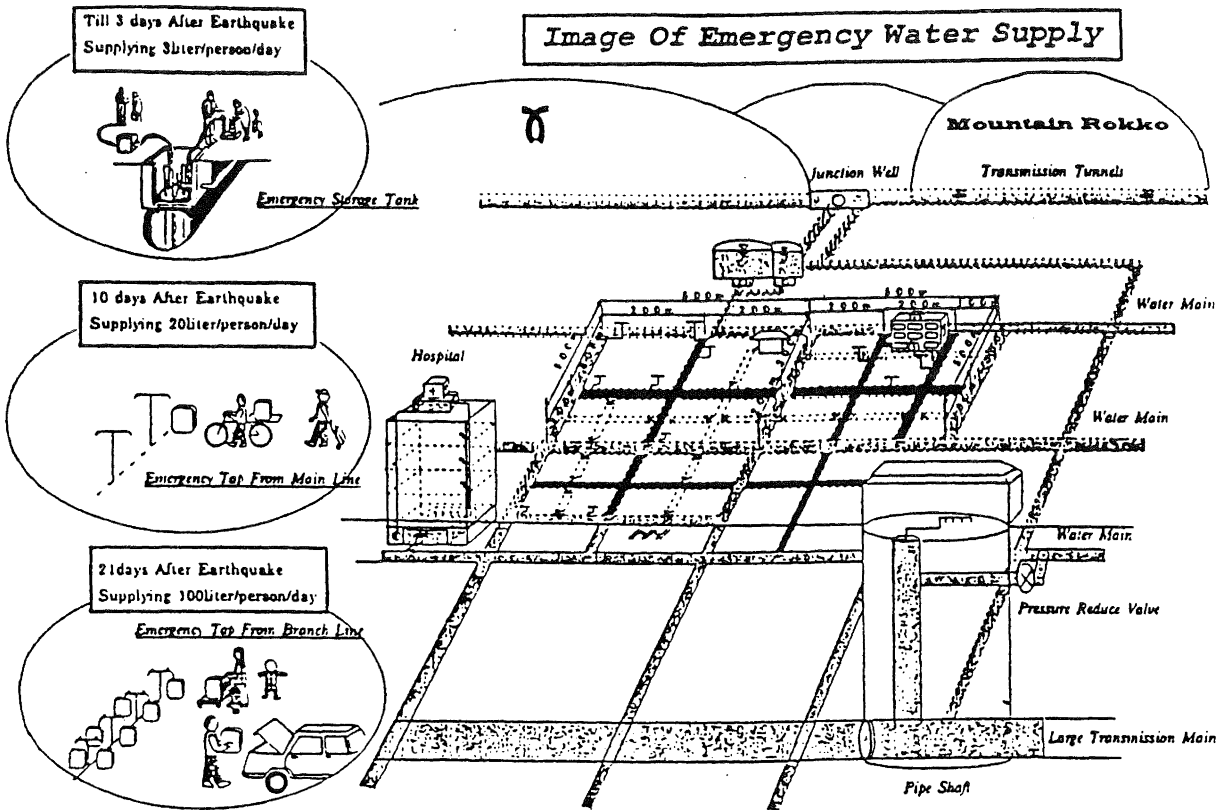


FIGURE 3.6 Image of Emergency Water Supply using earthquake-resistant pipe-network (from Kobe Waterworks Bureau)

### *Keeping People Informed*

Information gained from Kobe officials sets out the various questions received from residents in the period after the earthquake as well as the steps taken to inform the public of progress with restoration. This will be most helpful in further developing response plans in New Zealand.

### *Plans for the Future*

By March, Kobe City Waterworks Bureau had prepared "Guidelines for Earthquake Resistant Waterworks in Kobe City" as well as its associated "Working Plan". These will be translated into English.

The essential features of the plan described below are shown in Figure 3.6.

- For the first 3 days after an earthquake, provide 3 litres/person/day
- 10 days after the earthquake, 20 litres/person/day
- 21 days after the earthquake, 100 litres/person/day
- Construct an additional large transmission main through urban districts with associated facilities so that people can be supplied with water from this main immediately after the earthquake.

### **3.5 Interdependence Issues**

A number of interdependence issues were highlighted during this earthquake for water supply.

#### *• Roothing*

Disruption to roads caused difficulties for repair teams travelling about the city, for materials being transported to the city and for emergency water tankers supplying water.

#### *• Port*

The port was used to supply some of the emergency water as well as some restoration materials.

#### *• Telecommunications*

As noted previously the communication system for operating Kobe's water supply system is largely independent of the telephone network. However, with the Waterworks Bureau offices being destroyed in the earthquake, there were considerable constraints with only one telephone line and one fax line being allocated to Waterworks for the first 2 weeks after the earthquake.

#### *• Electricity*

Electricity did not appear to be a problem for Waterworks as it was restored very quickly. In addition, most waterworks' facilities requiring power are interconnected on a two independent lines basis.

### **3.6 Lessons for New Zealand**

#### *• Response Planning*

The importance of high quality response planning was again highlighted. Major New Zealand cities, and in particular Wellington, could not rely on such rapid and extensive assistance that Kobe had. This makes it even more important that response planning and mitigation measures are of a high standard and that annual exercises and audits are held.

#### *• Personnel Response Time*

Approximately 50% of the waterworks staff managed to get to work on the first day of the earthquake. This needs to be taken into account in response planning.

#### *• Detailed Mitigation Measures*

The following detailed measures have been identified taking into account lessons learnt from both Kobe and Northridge (1994) and applying them to New Zealand situations.

#### *Treatment Plants & Pumping Stations*

- Bolt Down Equipment etc. - this includes all pipes and machinery as well as internal fittings and furniture.
- Provide Flexible Joints Where Appropriate - while it is important to bolt down equipment, pipes, machinery etc., it is also important to provide for earthquake induced movement through flexible joints etc.
- Provide Standby Power - have all essential features backed up by standby power which is tested regularly by those who will be operating it in an earthquake situation.

#### *Reservoirs*

- Upgrade older existing reservoirs to be seismically resistant as necessary, providing flexible joints where appropriate, e.g. at inlet and outlet pipes.
- Investigate feasibility of installing two tanks or dividing single tank to provide emergency water supply which can be cut off and retained while at the same time also providing water for fire fighting purposes.
- Install cut off valves which are activated by flows typical of a large downstream break.

#### *Pipe Reticulations*

- Bolt or tie down all above ground reticulations.
- Provide for flexibility and movement where appropriate. In Kobe, flexible joints for connecting the water supply from a water main to a building have been developed.
- Have programmes to replace earthquake deficient materials such as cast iron pipes etc.

#### *• Preparedness*

- Have appropriate spares strategically located.
- Have plan records in strategic places.

- Have suitable communication systems in place. This may include arrangements to ensure priority to cellular network. Communication systems should also be compatible with those of mutual aid organisations.
- Develop mutual aid agreements with companies and organisations that are likely to be able to help.
- Develop media plans and test.
- Recognise that Utility staff will be fully occupied with inspection and repair. This means there will need to be plans for others to undertake distribution of potable water to those needing it. In Kobe, the Waterworks Bureau did both but in Wellington present plans are that Civil Defence would look after Emergency Water distribution during the response and recovery period. The interface between water supply managers and emergency managers requires further consideration.

- *People Aspects*

- Place emphasis on preparing for and looking after personnel in the earthquake situation. This includes providing adequate food, potable water, shelter, and hygiene facilities for those remaining at work for extended periods. It is also important to provide means by which workers who are likely to be away from their families for long periods can communicate regularly with them. In the Kobe situation the provision of food and basic hygiene facilities was marginal in the first few days after the earthquake for people working 16 hours per day and only going home once every 3 days.
- "People want to be part of the solution not part of the problem". In accordance with this objective, the response plans need to be prepared with an emphasis on staff knowing they have the authority to get on and repair key facilities rather than having to get management approval at each stage. Management also needs to be careful not to interfere with staff who will be best at undertaking repairs.
- Educate the public at large that for at least the first three days and may be for up to a week after a major earthquake, the water supply will be at best unreliable and they should be planning to look after themselves.

## 4 WASTEWATER SERVICES

### 4.1 Network Description

Sewerage and stormwater drainage services are managed by the Sewage Works Bureau of the City of Kobe. Kobe is separated into two general areas by the Rokko Mountain range. The area lying on the coastal side is the densely populated, heavily urbanised 'old' city which was hardest hit by the earthquake. The inland and northern sides of the range was developed to accommodate post-war growth.

The city is divided into eight treatment areas, two of which are connected to regional sewerage schemes administered by the South Hyogo Prefecture (Regional Council). Statistics of the drainage infrastructure are as follows:

- Total urbanised area 19,500 hectares
- Area served by sewerage system 16,000 hectares
- Population 1.51 million

- Treatment plants 7 (plus 1 sludge incineration plant)
- Pumping stations (dry well) 24 (12 sewage, 9 stormwater, 3 dual purpose)
- Length of sewers 3,300 kilometres, 180,000 manholes
- Total length of stormwater drains 484 kilometres, 20,000 manholes
- Volume of sewage treated 540,000 cubic metres/ day

The sewerage system is relatively new, with only 22% being reticulated prior to 1969. Today the sewered population rate is 97.4%. The piped public sewerage system is constructed of the following materials:

- Main sewer 300km. - Almost all reinforced concrete socket rubber ring jointed pipes.
- Local sewers 3,000km - 1,600 km reinforced concrete socket rubber ring jointed pipes.
- (0.2 to 3m dia.) - 1,000 km PVC socket jointed pipes with rubber rings.
- 400km earthenware socket jointed pipes (~50% mortar seal).
- Stormwater 484 km - Mainly reinforced concrete pipes and concrete box sections.

The City of Kobe maintains the sewerage system to the inlet side of the inspection chamber located at each property boundary.

### 4.2 Damage Assessment

Sewerage and stormwater drainage assets were heavily impacted by the earthquake. The total estimated cost of the damage sustained is NZ\$670M, representing 8% of the replacement value of the systems. As would be expected, the severity of damage was closely related to the high risk geological zones; namely the liquefaction prone reclaimed islands and port area, and the narrow coastal strip of alluvial soils running along the base of the Rokko mountains. Damage was also higher along the paths of old streams, possibly due to the higher water table. The information below is the status as reported in July 1995 [Kobe Sewage Works Bureau, 1995].

#### *Sewers and Stormwater Drains*

Knowledge of the full extent of damage is incomplete and it is anticipated that many problems will come to light in time. The reclaimed islands generally settled uniformly and there was much less damage than could have been expected. There were no known instances of pipes floating. The typical nature of damage was:

- Pipe faults: joint opening, circumferential cracks and multiple fractures.
- Accumulation of sediment in pipes due to the inflow of soil and sand through open joints and clogging of laterals where houses have collapsed.
- Sheared pipes at junctions and connections with manholes, inspection chambers and buildings.
- Manholes: Uplift/settlement in liquefaction areas, lateral displacement of slabs and rings.
- Failure of support structures (e.g. bridges, elevated highway & underground station).
- Failure of above ground pipes due to inadequately braced fixing details.

- Tunnel: Minor longitudinal and circumferential cracks in bored tunnels on reclaimed island.
- Stormwater outlets: Dislocation of pipes due to lateral spreading of stream embankments and sea walls (particularly in the port area).
- Stormwater culvert: Tilting and fracture of side wall slabs.
- Collapse of stone masonry stream bank walls.

The impact of the damage was a 20% increase in dry weather sewage flows. Concrete and plastic pipes generally survived well, and the majority of damage occurred with earthenware pipes.

Although a detailed analysis of damage is still lacking, some useful macro statistics are available. Based on the results of investigations completed up to July 1995, damage ratios were higher for small diameter pipes (4%) than main drains (2.4%), probably because they are laid at less depth and involve a much higher percentage of earthenware pipes. The incidence of urgent repairs city wide was 2.6 /km for sewers and 0.7 /km for stormwater, with the ratio being as high as 17 /km for sewers in the most severely damaged district.

#### *Pump Stations*

Twenty of the 24 stations were damaged, six being out of commission immediately after the earthquake. Total damage is estimated at NZ\$25M to \$30M, most of which was to replace or repair machinery. Sheared driveshafts and water damaged electric motors were common failures. The number of external pipe connections damaged was not available.

#### *Treatment Plants*

Three of the 7 treatment plants and suffered partial or full loss of function: Higashinda (100% loss of function), Chubu (50%) and Seibu (20%). These stations, which provide 63% of Kobe's treatment capacity, are all located on reclaimed land, as was the heavily (63% loss of function) damaged Tobu sludge incineration plant on Rokko Island. There was up to 1 metre of ground settlement at these plants. Three of the undamaged plants were located outside the main damage area and the fourth is on the man-made Port Island where there was 500-600mm of uniform ground settlement.

The nature of the damage that caused the loss of function was:

- Separation of expansion joints in reinforced concrete sedimentation & aeration tanks.
- Foundation damage destabilising buildings and structures.
- Collapse of canal running through plant, damaging adjacent plant and pipes (Higashinada).
- Destruction of roading and underground piping by ground settlement.
- Flooding of pump chambers due to failure of pipes in the corridors connecting underground treatment facilities (at Higashinada 97 pumps, 161 control panels, 64 instruments and 67 automatic valves were flooded).
- Fracture of pipes interconnecting structures (aeration & sedimentation tanks, dewatering plant) due to varying earthquake response of those structures. At Seibu two flexible interconnections survived while six concrete ones failed.
- Dislodgment of sludge scrapers.

However most of the structures survived relatively undamaged.

### **4.3 Effectiveness of Mitigation & Preparedness Measures**

Kobe was unprepared for an earthquake of this intensity, with planning based around scenarios for typhoons and smaller quakes. The mutual support agreements with other major cities proved invaluable and the recovery of wastewater services was not restricted by a lack of manpower, materials or plant. Support was received from 30 cities and it is intended to expand the number and scope of these agreements.

The value of dynamically consolidating reclaimed land beneath structures was proven by the lack of damage to the treatment plant on Port Island.

Although staff mobilisation plans were in place, congestion of the traffic network and the residential damage suffered by many staff meant nearly half were unavailable on the first day.

There was no evidence of upgrading work to mitigate the vulnerability of drainage assets to earthquake damage. The City efficiently got on with the recovery despite the lack of pre-planning, and the effectiveness of their efforts can be judged by the availability of pumping stations and a reasonable functional network when water services were restored (other than treatment plants).

### **4.4 Response and Recovery Aspects**

The Bureau set up an emergency organisation on the day of the quake to tackle the task of damage assessment and restoration. Resources were initially applied as follows:

<b>Emergency Function</b>	<b>Task</b>	<b>No.</b>
Information liaison Rescue	Handling communications between Bureau & City Hall	20
	Assisting at refugee centres, ward offices	30
Private drainage assets Pipe assets	Handling damage reports and organising repairs	10
	Damage assessment, handling notifications & emergency remedies	130
Treatment/ pump stns. Administration	Damage assessment, determining emergency remedies	40
	Oversee operation of plants & stations, damage investigations and organising emergency repairs	230
	<b>Total</b>	<b>460</b>

The Sewage Works Bureau has permanent staff of 120. Assistance was received from local and central government, and a peak total of 4000 staff was achieved (2,000 design/ office and 2,000 field staff).

The damage was studied in three stages:

- **Emergency study:** On the day of the quake an inspection of treatment plants and pumping stations was undertaken by night shift staff and those who managed to show up early on the day of the quake to assess the availability of function and security of chemicals, digester gas and city gas. Staff then started restoration of function as best they could. The emergency study for drains focused on sewer mains.

- **Primary study:** Conducted for about one week after the earthquake to understand the broad scope of the damage. Several groups of engineers checked concrete structures, machinery and plant. For drains the primary inspections were designed to determine the range of the secondary study, and it centered on a visual inspection from manholes.
- **Secondary study:** This phase, which is still underway, was to assess the overall picture of damage and to all assets and to initiate design for rehabilitation work. The scope of the secondary study for drains was a primary area of 4,120 hectares covering the man made islands and the heavily damaged coastal strip. The first inspection phase was again visual from manholes, followed by CCTV inspection of drains exceeding a set damage rating criteria. Sixty kilometres of CCTV inspection was completed in the first six months, utilising 37 cameras which achieved an average of 200m /day.

Aerial photos of surface damage, which were available the day after the quake, and road distortions were useful indicators of underground damage. The Bureau did not have a GIS capability. Investigations were initially hampered because the few passable roads were flooded with traffic that effectively paralysed the traffic network.

The recovery was effective despite the lack of pre-planning, and staff do not seem to be contemplating any significant effort towards preparing new emergency procedures. Priority was given to restoring the main components of the sewerage system, and fortunately there was low rainfall after the earthquake. Sewerage recovery was aided by the lack of water supply, and no major sewage overflows occurred.

All treatment plants and pumping stations were operational by 1 May and were available as sewage flows resumed as the water supply was restored. Full scale rehabilitation is ongoing; pump stations and treatment plants will be completed by March 1996 with the exception of the Seibu (March 1997) and Higashinada (March 1998) plants.

In the first six months of the recovery, 530 pipe repairs and 1,400 manhole repairs were undertaken. Damaged sewers on bridges were temporarily restored within 10 days. However the full extent of damage is not yet understood, and there is concern at the potential for cavities to form where pipes have separated. An intensive programme to inspect lateral junctions and connection points was undertaken, and 4,300 (3.5%) faults were found and repaired out of 120,000 inspections. The great majority of junctions remain unrepaired, and 2 year plan is being prepared to fix these now.

#### 4.5 Interdependence Issues

The delay in the resumption of water services assisted efforts to repair sewers. Close liaison was required with the Water Bureau as much damage to sewerage services became apparent as water services were restored.

The Public Works Bureau called regular meetings of key utility operators to give briefings and coordinate emergency repair plans. Agreements were reached that road reconstruction should be delayed where possible until underground services have been reconstructed and that formal approvals for trenching could be waived for emergency work.

Coordination of works programmes were particularly required where:

- Roading: Repair of sewers located on failed structures (bridges and motorways).
- Port: Repair of stormwater drains damaged by lateral spreading and movement of sea walls in the port area need to be coordinated with port reconstruction.

The initial response was heavily restricted by traffic congestion, and the loss of the main highway links is still hindering the delivery of materials and movement around the city.

The cellular phone network was not reliably available on the first day due to overloading by heavy private use, and field communications were limited to hand-held radio telephones.

Sewer pipes over bridges appeared to fare well. These pipes are mainly steel, with polyethylene being used more extensively now.

- Provide robust flexible joints at the interface of pipes and structures/ machinery.
- Where structure is to be built on poor ground, special attention is to be paid to soil consolidation and the foundations.
- Securely fix pipes, mechanical and electrical equipment, furniture, computers, etc.

#### General

- Wellington and New Zealand generally must be concerned about the effects of liquefaction on sewerage and stormwater drainage systems. The generally uniform settlement in the man-made islands at Kobe is most unlikely in New Zealand soils and older reclamations. In addition most new Zealand sites, and Wellington in particular, have older systems with a higher proportion of brittle pipes.
- The main stormwater drains in the central business district and older section of Wellington are particularly vulnerable. Kobe did not receive heavy rain during the initial recovery phase; we are unlikely to get such favourable weather and the impact of failure will be high.

#### 4.6 Lessons For New Zealand

##### Preparedness

The scale of the damage and lessons learnt in Kobe reinforces the need for well prepared and tested response plans. Specific preparedness points that can be learnt from Kobe include:

- **Resource Planning:** The immense resources of manpower, materials and plant available to Kobe from 38 major neighbouring cities allowed the recovery of drainage services to proceed without restriction. Major New Zealand cities do not have this luxury and need to put in place mutual support agreements and contingency plans for resources.
- **Traffic control planning:** The securing of priority traffic routes for emergency and essential service crews is vital, particularly in the initial response period.
- **Temporary Services:** There is value in contingency planning for servicing temporary housing and the provision of portable toilets.

- **Communications:** Ensure availability of suitable systems.
- **Damage Assessment:** Kobe's experience highlights the need for reliable preplanned impact assessment programmes, including survey methodology, criteria for damage estimation and training. The value of aerial photographs was highlighted in Kobe and it is desirable to have prior arrangements in place to have a disaster area flown.
- **Public information:** Preplan public information strategies and material for different phases of response, restoration of services and repair of private drains.

#### Mitigation - Sewers and Stormwater Drains

- Replacement/strengthening programmes are needed to ensure critical drains retain their function after an earthquake event ('critical' being defined as those drains for which, because of their size, location or function, failure will have an unacceptably high financial, service or environmental impact).
- Flexible design details should be used for joints between pipes and structures (pump stations, manholes, chambers, etc.)
- Use appropriate materials, particularly in liquefaction prone areas (e.g. HDPE, PVC).
- Design local sewers, lateral, manholes and inspection chambers to facilitate repair.
- Special attention should be given to the design of attachment details of above ground drains at fixed to structures.

#### Mitigation - Pumping Stations/Treatment Plants

- Consider options to provide redundancy in the rising main network to allow diversion of sewage in the event of pump station or rising main failure. Kobe will consider interconnecting treatment plants to allow diversion of flows.
- Design facilities to minimise the risk of damage to electrical and mechanical equipment in dry well pumping stations.
- Provide standby power for key pump stations & essential treatment plant components.

Sufficient resources were available to do all work required, and the equivalent of 10 years normal work has been done in six months. The majority of repairs were driven by service complaints (14,500 up to the end of May) received as the water supply was restored. 200 contractors were available to fix these problems.

Central Government subsidies have been available for demolition (100%) and restoration of services to pre-earthquake condition (80% for two years), and there is currently a high level of activity to take full advantage of subsidy. Earthenware pipes are no longer being used, with PVC being the preferred material for local sewers.

3,000 portable toilets were gathered nationally by the Solid Waste Bureau and located strategically throughout Kobe, particularly at schools used as refugee centres. Chemicals were poured into school swimming pools to provide a basic sewage

treatment facility. At the Higashinada treatment plant a section of the adjacent canal was sealed off and chemicals poured in to dose the sewage. Temporary screens and a borrowed belt dewatering press completed the process.

The Bureau did not assist with the repair of private drains and there is no precise picture of the state of these drains. Information supplied by the Plumbers Association indicated that a peak of 4,800 repairs were completed in February. City staff were dispatched to liaise with the Association and help with public information. Not surprisingly, contractors prices went up and there were a lot of complaints from property owners.

## 5 TRANSPORTATION NETWORKS

### 5.1 Network Description

#### 5.1.1 Airport

The two airports in the area are:

- Itami Airport (previously Osaka International Airport) located just to the east of the heavily damaged area, and now a domestic airport.
- Kansai International Airport, a new facility located 27 km south of Kobe on the opposite side of Osaka Bay. It is built on a reclaimed island with road and rail linkages and a sea ferry linkage. It handles air cargo and passengers.

It has 33 boarding gates and a total terminal length of 1,672 metres and covers 511 ha. Built over a three year period, it overlays soft weak clays compacted by a sand pile surcharge system. Subsidence prior to opening was 10 metres, and a further 1.5 metres is expected over the next 30 years. Hydraulic jacks are attached to 900 columns to counteract differential settlement of the terminal building.

The access link is 3.75 km long with a 2.7 km double deck trussed section bridge with road and rail on each deck. Six lanes, a number of rail tracks and electricity, water and gas services also cross this bridge.

There appears to have been little or no damage to airport facilities, with flights being disrupted only on the day of the earthquake while road and rail routes were closed for precautionary inspections.

#### 5.1.2 Rail

There are a number of east-west routes passing through Kobe (Figure 5.1):

Description	Ownership
JR Shinkansen * (Bullet Train)	Japan Rail (Government owned)
JR Tokaido * (Main Trunk)	Japan Rail (Government owned)
Hanshin Railways	Privately owned
Hankyu Railways	Privately owned

(\* These routes are national linkages)

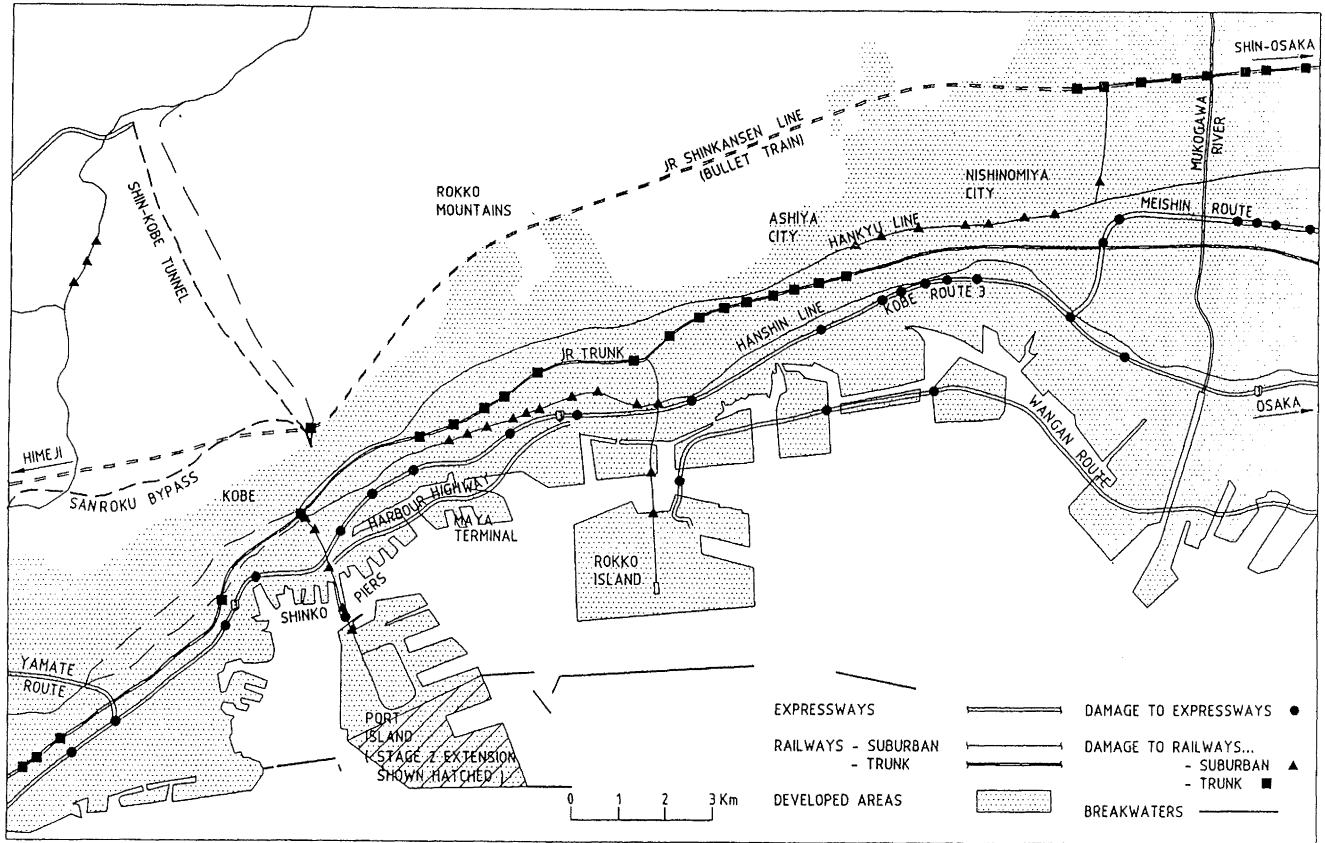


FIGURE 5.1 Damage to primary transportation routes in the Kobe area [Billings, 1995] and port layout

In addition there are a number of more local and north-south feeder lines and freight linkages to land based Port areas (other than the Islands).

Generally the rail systems are people movers, while the road system carries both people and freight.

All passenger services are electrified.

Some of the JR Tokaido line is located on embankments.

There are also two 'new transportation systems', Port Island Liner and Rokko Island Liner serving these islands. They operate automatically and are in fact 'guided busways'. They were built by the City of Kobe.

The two Island Liners are entirely located on elevated structures.

**5.1.3 Road**

A number of east-west arterial routes pass through Kobe (refer Figure 5.1), with connections to the Port for road freight. Freight transport is an important function of the road network, with some 22% of total road freight in Japan passing through Kobe.

Hanshin Expressway Public Corporation	
Osaka-Kobe Route (Route 3)	Principal link to Osaka, major through route.
Wangan Route (Route 5)	Coastal link to Osaka and Kansai International Airport.

Japan Highway Public Corporation	
Meishin Expressway	Bypasses Osaka to north-east.
Chugoku Expressway	Northern bypass route.

Ministry of Construction	
Highway 43	At grade highways linking Kobe and Osaka, these routes merge in places. Includes the Kobe-Yamate bypass (elevated).
Highway 2	

City of Kobe	
Harbour Highway includes:	Elevated, connects Rokko and Port Islands.
• Kobe Ohashi Bridge	• Port Island connection to Expressways and other roads.
• Rokko Ohashi Bridge	• Rokko Island connection.

There are essentially four types of road in Japan:

(a) *Expressways (toll roads)*

These are operated by four private corporations in Japan, the two operating in the Kobe-Osaka area being the Hanshin Expressway Public Corporation (HEPC) and the Japan Highways Public Corporation (JHPC). In the Kobe-Osaka area these are essentially elevated structures.

Tolls are relatively expensive (\$NZ18 for a trip from Osaka to Kobe), but because of congestion on other roads toll roads are extensively used. The toll revenues are set to include a payback for the cost of construction.

Most expressways in the Osaka-Kobe area are operated by HEPC which has a sophisticated electronic surveillance and traffic conditions monitoring system. It is able to provide up to date information to users on levels of congestion and travel times via overhead electronic signs, telephone enquiry, console stations and by radio.

Around 900,000 vehicles used the Hanshin Expressways prior to the earthquake. The 'historical cost' value of the HEPC network is \$NZ21 billion.

(b) *National Highways*

Operated by the Ministry of Construction for the Government, Highways 2, 43 and 175 pass through Kobe.

(c) *Prefecture Highways*

Operated by the Hyogo Prefecture in Kobe, similar concept to 'regional roads', but operating extensively throughout Japan. There are no Prefecture Roads in Kobe, the City being one of twelve designated in Japan to have full control.

(d) *Local Roads and Highways*

These roads are operated by local authorities such as the City of Kobe.

## 5.2 Damage Assessment

The locations of the main areas of damage to the primary transportation routes are indicated in Figure 5.1.

### 5.2.1 Railways

(a) *Shinkansen (Bullet Train) (Osaka/Kobe/Himeji)*

Tunnels	31 km	Lining damage some locations.		
Concrete Viaducts	38 km	Column shear failures:		
		Undamaged sections	1,119	89%
		Shear failures (no collapse)	131	10%
		Shear failures (with collapse)	13	1%
<b>Total</b>		<b>1,263</b>	<b>100%</b>	
Bridges	14 km	Damage to piers at several locations.		

(b) *JR Trunk Line*

Heavy damage to railbed (particularly embankment distortion and settlement), viaducts, bridges, stations, electrification system and workshops.

A critical section of 2.3 km elevated viaduct between Sumiyoshi and Nada Station suffered severe column damage and collapse of several sections.

Repair costs for Shinkansen and Trunk Lines total \$NZ2 billion.

(c) *Hankyu Railway*

Damage at several locations, severe column shear failures and collapses of several viaduct sections, \$NZ710 million repair costs.

(d) *Hanshin Railway*

Damages at several locations, \$NZ920 million repair costs.

(e) *New Transportation Systems ('Liners')*

Port Island Liner structures were seriously damaged, including failure of reinforced concrete piers, downwards displacement of girders and unseating of a continuous beam from its bearings.

At the bridge to Rokko Island, a pier moved laterally causing collapse of the main bridge span.

### 5.2.2 Roads

(a) *Hanshin Expressway Public Corporation*

There was damage to structures on all 13 routes operated by the HEPC, covering 200 km and located within 60 km east of the epicentre. The large majority of damage occurred on Kobe Route 3 and Wangan Route 5.

(i) *Osaka-Kobe (Route 3) Mukogawa to Tsukimiyama 27.7 km*

Damage Levels [Iemura et al, 1995]	Undamaged	Damaged Repairable	Damaged Demolished	Total
Piers damaged	365 (31%)	650 (55%)	160 (14%)	1,175
Spans damaged	105 (8%)	1,100 (84%)	100 (8%)	1,305
Bearings damaged	100 (10%)	700 (70%)	200 (20%)	1,000
85% of the piers are reinforced concrete, the remainder being steel. The concrete piers fared worst, the severe damage rate being twice that for steel. [Ishizuka et al, 1995]				

The most severe (ranked as in *Handbook of Earthquake Countermeasures for Roads (Disaster Restoration)*, Japan Roadway Association, February 1988) superstructure damages were [Ishizuka et al., 1995]:

- Complete collapse of 18 spans (635 metres) of elevated Expressway at Fukae Honmachi, Higashinada-ku, Kobe.
- Collapse of two simple girders at Takase-cho, Koshien, Nishinomiya due to damage to reinforced concrete piers.
- Collapse of two simple girders at Honmachi, Nishinomiya due to large horizontal movement.
- Collapse of four spans of the rigid-frame beam bridge at Hatoba-machi, Chuo-ku, Kobe because of damage to the single reinforced concrete columns.
- Partial falling of the two-span continuous box girder, curved bridge at Minatogawa Ramp, Nagata-ku, Kobe because of damage to the reinforced concrete piers.
- Two simple girders were close to falling at Niwa-machi, Nishinomiya because of the settling of damaged steel piers.

Most of these structures were designed to meet 1964 (or earlier) codes, with 17% being to 1971 codes. It is clear that these structures which were designed in the 1960s and 1970s suffered significant damage, of a level to justify close analysis of similar age structures in New Zealand.

(ii) Wangan Route 5 (Mukogawa to Rokko Island Kita) 14.3 km

Damage Levels [Iemura et al, 1995]	Undamaged	Damaged Repairable	Damaged Demolished	Total
Piers damaged	309 (84%)	57 (16%)	0 (0%)	366
Spans damaged	425 (92%)	36 (8%)	1 (0%)	462
Bearings damaged	229 (51%)	180 (40%)	42 (9%)	451

Major damage was [Ishzuka et al., 1995]:

- Damaged cast steel pivot bearings and tilted and shifted piers on the Nishinomiya-ko Bridge (a Nielsen-Lohse arch bridge).
- Damaged webs of rigid frame steel piers, deformed pendulum bearings and pulling away from pins on the Higashi Kobe Bridge (a three-span continuous cable-stayed bridge).
- Damaged bearings, main trusses falling off the bearings and shifting horizontally on Rokko Island Bridge (a Lohse arch bridge).

308 piers (84%) were designed to 1980 standards, with the remaining 58 designed to 1990 standards.

Damage levels were significantly lower than on Route 3 above, confirming the more resilient design characteristics of 1980s and 90s codes.

(iii) Foundation Damage

Nil or very slight damage - 92%.  
Shearing/distortion - 8%.

(iv) General Damage HEPC Routes

- Kita-Kobe Route (Route 7) - cracks in prestressed concrete bridges, sheared bearings, earthworks subsidence; overall a light level of damage.
- Osaka Prefecture - cracks in piers, strained girders, bearings and expansion joints destroyed (mostly north Osaka).
- Traffic volumes using the HEPC network were estimated to have fallen from 920,000 to 500,000 per day in March 1995 reducing toll revenue by \$3.2 million a day.
- Restoration costs were assessed in March at \$4.3 billion with further retrofitting work at \$3.1 billion. (Ref 9)

(b) Japan Highways Public Corporation

(i) Meishin Expressway (4 Lanes) 20 km

Severe damage to 7 km section near Nishinomiya, column shear failures with up to 700 mm of superstructure settlement at critical piers.

Damage Levels	Undamaged	Damaged	Total
Piers (reinforced concrete)	1,131 (71%)	457* (29%)	1,588
Bearings (metallic)	1,845 (54%)	1,594 (46%)	3,439
* 99 severe including some partial collapses			

(ii) Chugoku Expressway (6 Lanes)

Damage Levels	Undamaged	Damaged	Total
Piers (reinforced concrete)	767 (74%)	277 (26%)	1,044
Bearings (metallic)	2,522 (54%)	2,131 (46%)	4,653

None of the JHPC structures were designed to the modern (post 1980) codes. Repair costs total \$NZ1.6 billion.

(c) Other Highways

Other routes suffered damage to viaducts and bridges, but not as severe as the Expressway routes. Highway 43 was severely disrupted by the collapse of Kobe Route 5, as it runs directly underneath it for much of its length.

This situation was typical, with various elevated transport linkages being damaged and affecting others.

For example: the collapse of the Mondo viaduct deck onto a Hankyu Railway Line; transverse movement of double deck girders on Highway 2, Hamate Bypass; collapse of steel piers and superstructure at Iwaya Junction overpass.

(d) Minor Damages

There was very little damage to surface level roads, even in liquefaction areas such as Port Island where settlements of up to

0.5-0.6 metres occurred. With minor exceptions, these areas appeared to settle uniformly with little cracking or distortion of kerb lines, and little disruption due to underground services.

Exceptions occurred adjoining structures with piled foundations. Around bridge/viaduct piers, original ground levels were retained resulting in 'bumps'. Discontinuities also occurred at entranceways to buildings.

In other areas evidence of cracking of tiled surfaces was still visible and some cobblestone paths were disturbed. Concrete footpaths in some locations had been forced against kerbs, rotating them and riding up onto the kerb top. Again, this was the exception rather than the rule.

There was some damage to street furniture such as traffic light standards and signs.

(e) *Harbour Highway*

- Damage of reinforced concrete piers and fracturing of steel piers.
- Buckling of steel columns.
- Reinforced concrete piers of Second Maya bridge severely damaged.

(f) *Traffic Volumes*

The effects of the disruption to traffic on the 'east-west corridor' through Kobe is highlighted by the changes in traffic volumes in the Higashinada Nada Wards area, ie the vicinity of Rokko and Port Islands).

(g) *Reinforced Earth Structures*

Retaining walls constructed from reinforced earth used in approaches to several new bridges were observed to perform well.

**5.3 Effectiveness Of Mitigation And Preparedness Measures**

In general, the authorities were not prepared for the scale of the earthquake and the damage it caused. There had been no examination of 'weaker' structures built to codes earlier than 1980, when more demanding seismic standards were required. It was felt that the structures were 'impregnable' to natural disasters.

We were not advised of any such study or of any physical mitigation measures similar to those being carried out currently in Wellington and Christchurch.

This is perhaps surprising given the experiences in California and the design deficiencies such as lack of bridge column ductility and stirrup detailing.

Since the earthquake however, the Government, through the Ministry of Construction, has established design specifications which the authorities are required to adhere to both in restoring and rebuilding damaged structures and for retrofitting. These apply both to road and rail. The criteria are:

- Structures must not collapse under similar earthquake loadings to those of the Great Hanshin Earthquake, retaining continuity of design.
- Facilities must be able to continue operation without disruption.

Route	VOLUME AND CAPACITY		CAPACITY		
	September 1994	March 1995	October 1995 <i>Harbour Highway Part Restored</i>	June 1996 <i>Kobe Route Park Restored</i>	December 1996 <i>Complete Kobe Route Restoration</i>
Hanshin Expressway Route 3	115,000 (85,000) [4]	0 (0) [0]	(0) [0]	(85,000) [4]	(85,000) [4]
National Highway 43	78,600 (57,000) [8]	38,200 (29,000) [4]	(29,000) [4]	(29,000) [4]	(57,000) [8]
National Highway 2	33,000 (34,000) [4]	36,000 (34,000) [4]	(34,000) [4]	(34,000) [4]	(34,000) [4]
Yamate Route	24,500 (24,000) [4]	34,400 (24,000) [4]	(24,000) [4]	(24,000) [4]	(24,000) [4]
Harbour Highway	39,500 (46,000) [4]	0 (0) [0]	(46,000) [4]	(46,000) [4]	(46,000) [4]
<b>Totals</b>	<b>290,600</b> <b>(246,000)</b> <b>[24]</b>	<b>108,600</b> <b>(87,000)</b> <b>[12]</b>	<b>(133,000)</b> <b>[16]</b>	<b>(218,000)</b> <b>[20]</b>	<b>(246,000)</b> <b>[24]</b>

115,000 = actual traffic volume, vehicles/day

(34,000) = capacity, vehicles/day

[4] = No of lanes

The extent of the liquefaction and lateral spreading problem was also unexpected. The extreme levels of liquefaction induced damage to port seawalls and facilities designed and constructed in recent years is evidence of this.

HEPC advised that written disaster manuals were available and that annual training took place. However, the primary focus was typhoons, and the manuals were of little use in the event that occurred. What was written about earthquakes was inadequate because it did not envisage such an intense event.

The surveillance cameras of HEPC were rendered useless as the cables broke in the earthquake.

HEPC had a seismometer alarm which registered the shaking and sent a message to the traffic control centre, which is manned 24 hours a day. The operator immediately activated electronic road closed signs across the Expressway network. This was effective in warning motorists at the time, but more needed to be done in communicating information in the period following the earthquake.

#### 5.4 Response And Recovery Aspects

Traffic control initially was virtually impossible as vehicles that were unable to use the elevated Expressways used at grade roads instead. There was confusion with Police, whose first duty was the rescue of people, being unable to impose effective traffic control which hampered rescue, reconnaissance and emergency restoration work.

Staff of the Municipal Government made their way to City Hall during the first few hours by foot, cycle, motorcycle or car. Of much value was video footage taken by these people on their way in.

Logistical problems, such as the need to transport demolition and rebuilding materials on roads already congested markedly slowed the recovery process. From the roading congestion perspective, it was probably just as well that Port operations were dramatically curtailed because of damage. The roading system would have been unable to cope.

Because the damage to rail structures was less severe, priority was given to restoring rail routes for the movement of people. Rail services were restored as follows:

J R Trunk Line	74 days
Shinkansen (Bullet Train)	81 days
Hankyu Railway	146 days
Hanshin Railway	160 days
Rokko Island Liner	195 days
Port Island Liner	210 days (approximately)

Until road infrastructure is restored it is believed that there are still restrictions on traffic entering the Kobe area. Special passes are required and through traffic is required to detour behind the Rokko mountains, adding some 40 km to the journey.

The restoration of these services will have eased the congestion somewhat as commuters switch from cars back to trains. Very high volumes of Port traffic were observed to be coming back onto the roads as the Port recovers (now at 60% of pre-earthquake activity). At times almost one vehicle in two seemed to be a heavy freight/container truck.

It is clear that the collapse of essential overhead structures has had a dramatic effect, and unless adequate capacity and/or reasonably close alternatives exist then major problems will occur. This must be looked at in any New Zealand city with these sorts of structures.

The HEPC itself marshalled resources quickly to check damage on the closed Expressway networks, teams being despatched within 45 minutes. A Disaster Management Headquarters headed by the Chief Executive was established.

The Ministry of Construction acted quickly to reopen Highway 43, removing Kobe Route debris. HEPC advised that prior agreements with the Ministry of Construction worked adequately.

Initial restoration focused on preventing secondary disaster (eg by aftershock), bandaging damaged piers and propping structures and in providing a 24 hour monitoring system. This was primarily to protect traffic using the national highways under the Expressway. HEPC were responsible for the design and installation of the temporary propping, with the costs effectively being met by the Government. Expressways were progressively reopened with traffic initially being restricted to emergency vehicles.

Within two days 76 km of the 200 km network was able to be used by the public. This increased to 149 km (75%) by 12 February (26 days).

The Wangan Route 5 Expressway will not be fully operational until the end of October, while repairs to the Kobe Route 3 will not be completed until the end of 1996.

From 25 February a 'Lifeline route' for transporting essential supplies for people was established on the Kita Kobe Route, and a 'Revival route' for reconstruction supplies on parts of the Kobe Route 3 and Wangan Route 5 was set in place.

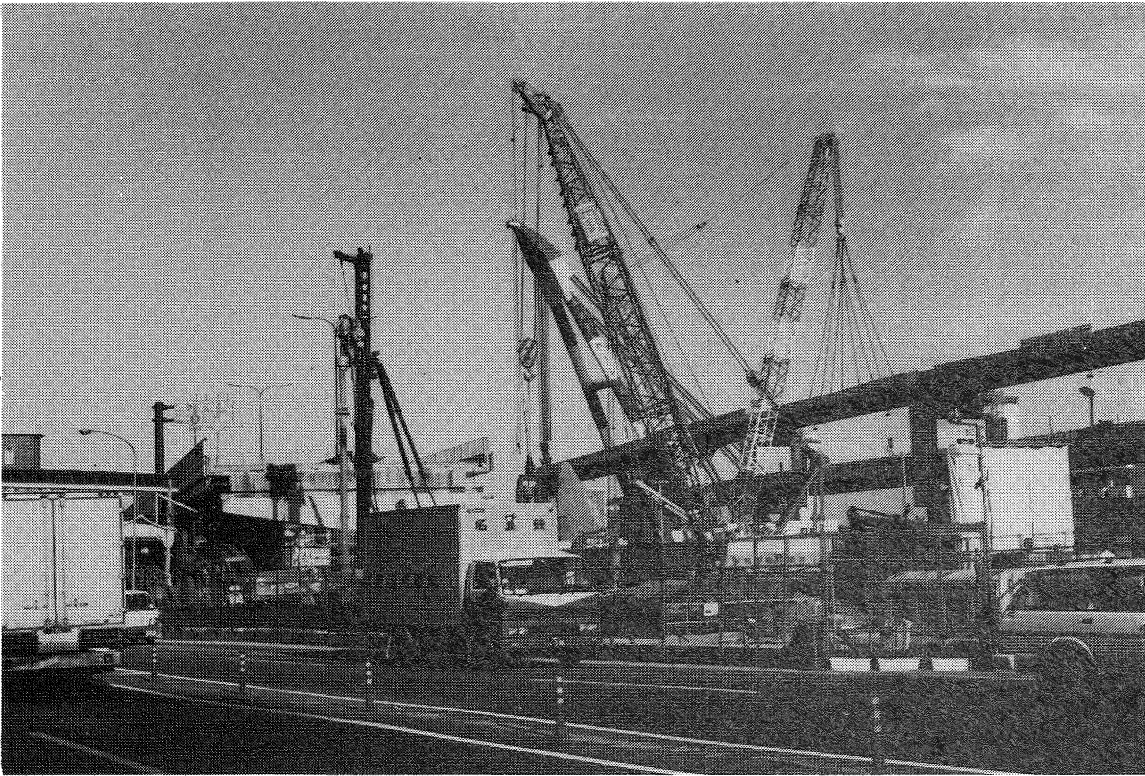
Figures 5.2, 5.3, 5.4 and 5.5 show typical aspects of restoration work now underway on the Kobe route.

Co-ordination between the Local and Prefectural Government, Ministry of Construction and Police authorities has been required to ensure that traffic capacity, safety and environmental considerations are taken into account.

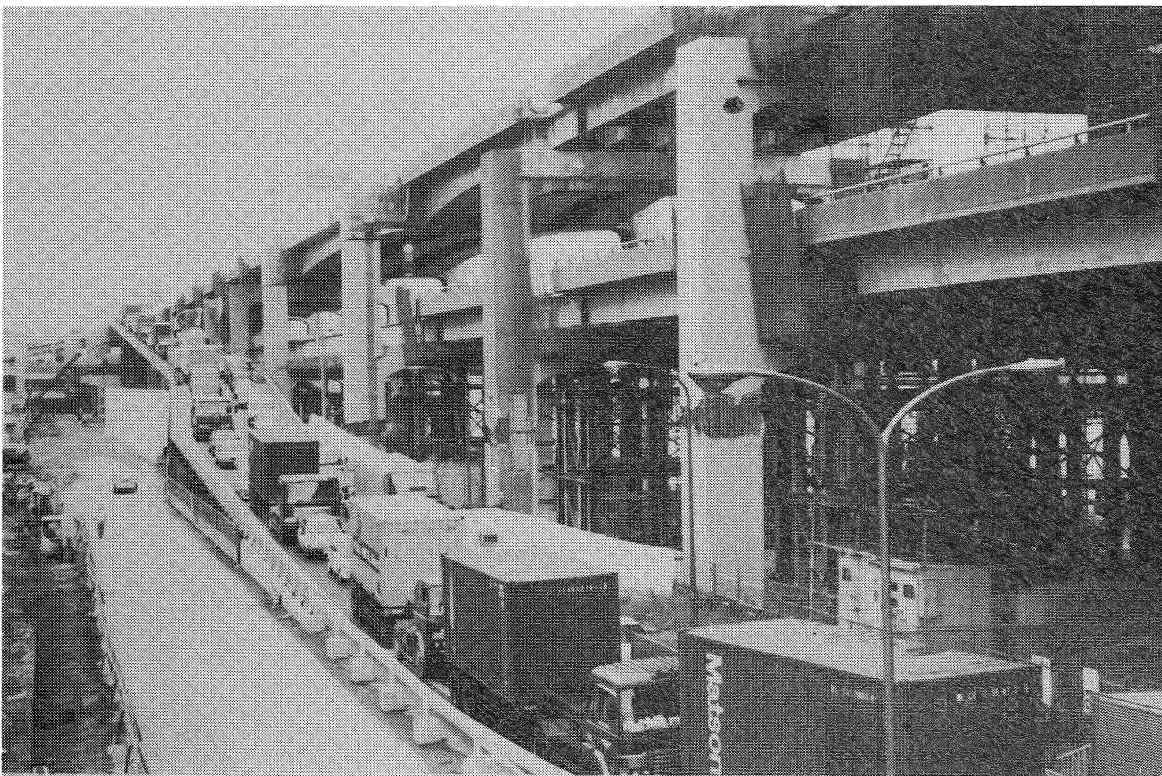
HEPC, as a commercial organisation, is now concerned about the loss of trust in its network and is anxious to properly safeguard all routes against future earthquakes. As well as repairing the damaged elements within a two year timeframe, HEPC have committed themselves to upgrade their structures to current standards within a three year period.

Typical measures adopted for the strengthening of reinforced concrete bridge piers to current earthquake standards include:

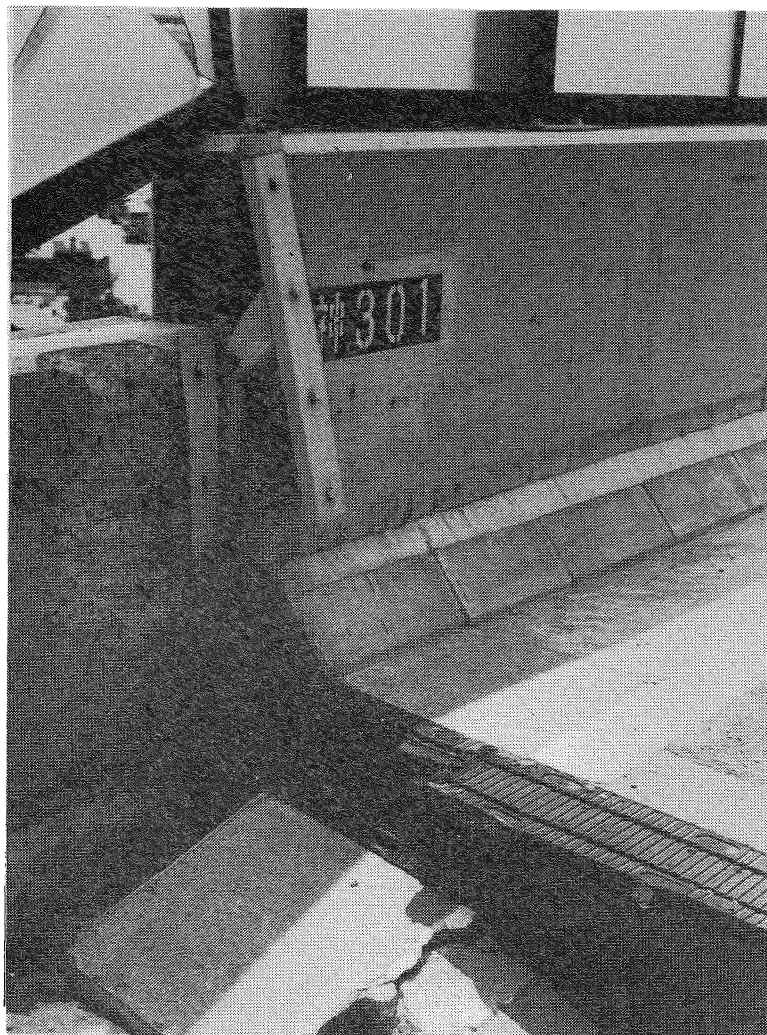
- Removal of damaged concrete and reinstatement of original longitudinal and transverse reinforcement.
- 30mm longitudinal reinforcing bars grouted into the existing foundation outside the existing column, and full strength welded to bars above for the height of the pier.
- Transverse reinforcement consisting typically of D16 bars at 150 mm centres added to confine new and existing concrete.



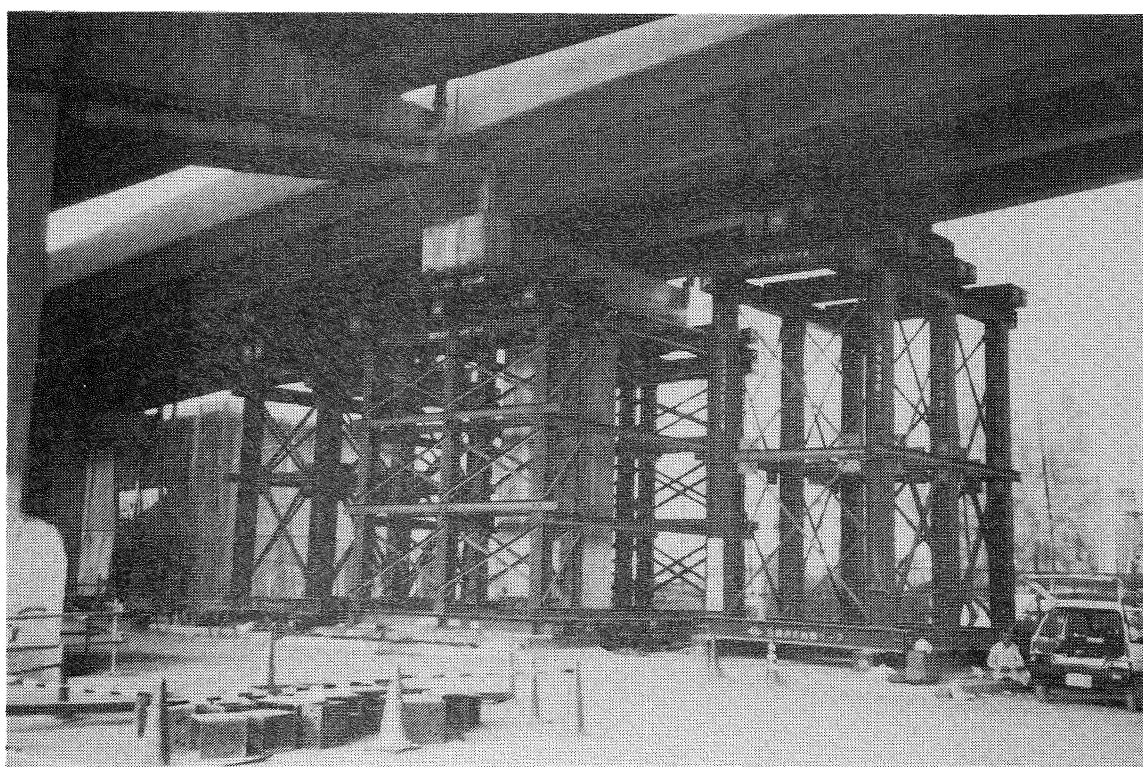
*FIGURE 5.2 Restoration work underway on Kobe Route 3. Highway 43 is at grade with the elevated Kobe-Yamate bypass in the background*



*FIGURE 5.3 Repair work underway on road linkages to Port Island, noting the severe congestion on the temporary route.*



*FIGURE 5.4* Damage at bridge deck connections, Kobe Route 3



*FIGURE 5.5* Propping of Kobe Route 3 expressway

- A 6 mm steel jacket and new concrete of average thickness 300 mm (depending on geometry of pier) added around the existing pier.

HEPC is looking at upgrading emergency facilities and evacuation guidance facilities. HEPC has also identified the need to enhance its disaster recovery manual and to make improvements to communication mechanisms with users following such events.

The costs of demolition (now complete) were fully met by the Government through the Ministry of Construction. The Government also funds restoration costs to the value of the standard to which the structures were initially built (estimated to be \$NZ1 billion). It is understood however that the estimated NZ \$6.4 billion cost of seismic upgrading, of both damaged and undamaged expressways, to current standards is to be met by HEPC.

It is clear that the scale of resources available in Japan to deal with the aftermath is enormous. Huge floating cranes are being employed to restore not only Port facilities but also sections of elevated roadway adjoining the coast. New Zealand's access to such resources will not be so easy.

### 5.5 Interdependence Issues

The severe congestion caused as a result of the collapse of many structures hampered the recovery of other essential services and the provision of emergency relief. It is also affecting the recovery of the local economy.

The first week after the earthquake was the most difficult. Gas supplies were cut, and food and water delivery and rescue activity was severely restricted.

Sea transport was important in bringing in emergency supplies and providing temporary accommodation for workers.

The current installation of a major underground services conduit (or 'lifespot') on Highway 43 is in turn affecting the congestion levels as work appears to be occupying one to two traffic lanes. This concrete conduit is designed to minimise the disruptive impacts of future earthquakes on underground services and in turn the roading system.

Overhead power reticulation generally behaved well (about 10% of total pole damage was due to breakage of the poles). Disruption to traffic tended to be in areas where fires and collapsed buildings occurred, bringing down wires and blocking road access.

Electricity was difficult to restore because of traffic congestion. The dominance of overhead reticulation, although much repair work was necessary, meant that service was restored quickly. It took four months to check all underground cables, suggesting that while overhead wiring will be a short term disruption to roads, it takes a lot longer to restore underground services.

It is believed that there may be significant amounts of minor underground service damage yet to be uncovered, possibly resulting in subsidence of road surfaces at some future time. In the case of large stormwater pipes, joints pulled apart and material fell (and may continue to fall) into the pipe, leaving a cavern above the joint. There are bound to be many pipes (especially smaller sizes not yet inspected by video) with damage that will require future excavation and repair.

Asbestos cement water pipes had all been replaced with ductile iron before the earthquake, largely because of the traffic disruption in repairing them. 'Strong' services pipes/ducts also help minimise damage to roadways.

Some drainage manholes formed using precast sections moved laterally and skewed (refer Wastewater). There was significant circumferential cracking of pipes. These damages will take time to repair and be potentially disruptive to traffic.

Drainage pipes fared better in newer areas, and even in liquefaction areas such as Port Island appeared not to disrupt the road system.

### 5.6 Lessons For New Zealand

- Recognise that a devastating earthquake could occur virtually anywhere in the country and have major impacts on transport and structures in particular.
- Recognise the possible short term and long term recovery aspects, impacts on people, the economy and the transport infrastructure itself of damage arising from such an earthquake. Look particularly at bridges and elevated structures, both road and rail. Identify the key Lifelines routes - for recovery and the economy.
- Recognise that elevated structures (eg bridges) built before the introduction of seismic design codes of the 1980s are likely to have significant damage levels in such an earthquake.
- Have pre-arrangements in place for heavy construction equipment and resources to be brought in from other cities/countries and ensure that this equipment can reach the site.
- Establish design standards for earthquake performance of bridges and elevated structures (eg ductility, bearing restraints) that will ensure vital structures survive a major earthquake, can be used by emergency traffic (including heavy vehicles) within several hours, and can be restored for normal use without severe disruption within days/weeks. This will require further work in terms of risk assessment and justification and may require Government support in terms of legislation/directive.
- Access controls must be placed as soon as possible after the earthquake event in order to allow access by emergency vehicles, reconnaissance teams and restoration resources.
- Rapid and effective communications are needed to alert the public of access restrictions on the roading network.
- The use of road status indicators for emergency communication to motorists on motorways and major routes is worthwhile.
- Long term controls on access routes may be needed - detours and other arrangements need to be thought about before the event and transport priorities established.
- Reconstruction efforts require restoration of a high standard of transport linkages. To minimise downstream economic losses, transport linkages need to be protected and routes for materials supply needs to be identified in advance.

## 6 PORT FACILITIES

### 6.1 Network Description

At the time of the earthquake the Port of Kobe had berthage for 250 large vessels with major trading routes handling a range of cargoes throughout the world. These facilities included 24 container berths at Rokko Island, Port Island and the Maya public piers, all major reclamations connected to the mainland at Kobe with substantial bridging. Together these three "island" reclamations alone (all developed since 1967) provided 375 hectares of port facilities under the control of the Port and Harbour Bureau of the City of Kobe. There is considerable berthage for conventional cargo vessels, ferries, passenger liners and shipyard repair along a substantial length of the Kobe waterfront area. This is addition to the newer port reclamations. Rokko and Port Islands include within their areas commercial, educational, housing and recreational areas with public transport (light rail) available to the city. The layout of the port area and the main piers is shown in Figure 5.1 in the previous section.

Foreign cargo handled through the port area totalled 169 million tonnes which is equivalent to approximately 28 ports of the size of Wellington in tonnage terms. The port handled 30% of the container cargoes in Japan (as quoted by Tokio Marine and Fire Insurance Co Ltd) with up to 2.5 million standard 6 metre containers (or TEU) handled per year. The container cargo represented 76% of the foreign trade through Kobe. Many of the shipping lines had container facilities dedicated to their own services, although there are public container terminals also available at the Maya pier. At the time of the earthquake there were 55 container cranes within the port.

The Port and Harbour Bureau has responsibility for the construction and maintenance of access bridging, and roading connecting the port reclamations and the mainland. Development plans were well advanced for the construction of Stage 2 of Port Island and much of the reclamation work associated with this project has been completed. In the future the Port and Harbour Bureau is to establish a local airport on an island reclamation beyond Port Island, again to serve the Kobe area. All freight to and from the main container berths is by truck with no rail delivery of cargo within the main areas of the port.

Organisation of the construction and repair of breakwaters lies with the 3rd District Port Construction Bureau of the Ministry of Transportation as part of Japan's sea defences against typhoon damage.

### 6.2 Damage Assessment Report

There was considerable settlement and/or liquefaction of the reclaimed areas of the Port. This settlement was accentuated alongside any well-engineered piled structures with drops of up to 2 metres to the settled reclamation against them. The new reclamations were faced with either gravity seawalls or caissons which had all been rotated outwards by the lateral earthquake force exerted by the reclamation. Lateral loadings of 15% gravity load had been allowed for in the design of these structures (as reported by port engineers). This lateral load allowance is now being increased to 25% as a result of analysis of this earthquake. The spreading of the wharf resulted in subsequent spreading of the legs of all the 55 container cranes at the port and the total collapse of one. All container berths were rendered inoperable as a result. Machinery within the

cranes was largely undamaged by the earthquake apart from that within the crane which collapsed.

Many elevated linkspans and gangways to roll-on roll-off berths were also dislodged with spans pulled off the support seating at one end by the lateral movement. Some undamaged piled wharf structures were however immediately useful and were available to assist in the relief effort. Pictures were shown of a naval water tanker berthed against a wharf supplying water to road tankers for distribution to the public immediately after the earthquake.

There are reports of damage to cargoes in containers affected by muddy water from the liquefaction of the soil and from containers sinking into depressions behind the wharf frontage. Some cargoes were also damaged inside collapsed warehouses, particularly at the Shinko piers.

Power to the Port areas was generally not available for up to two days in most areas until the city supply was re-established. Water supply however was out for longer due to damage in the main feeds across bridging to the main islands. Containerised refrigerated containers were therefore at risk as was cargo in cold stores which required water to operate. However, the very cold weather conditions at the time led to small rises in temperature, insufficient to adversely affect the cargoes stored.

Approach spans on the Kobe Bridge connecting it with Port Island were damaged, but with restricted access, limited traffic could use one lane each way within two days of the quake. The Rokko Bridge to Rokko Island was also undamaged, although it was eight days before heavy traffic could gain access without weight restriction. However, access to the Port area continues to be restricted by the central city congestion while the overhead expressways are under repair or being strengthened along the entire length of the city.

Ship building yards owned by Kawasaki and Mitsubishi were both damaged during the earthquake, including some minor damage to ships at the yards at the time. While both companies operate other facilities, commitments to existing ship building orders at these other yards will mean delivery delays to future orders.

Seawalls which provide protection from typhoons also settled as a result of the earthquake by as much as 2 metres. This was cause for some concern as their effectiveness in protecting against storm generated waves was reduced. Rapid measures to increase the height of these have been undertaken and this work had neared completion in time for the typhoon season.

### 6.3 Effectiveness of Mitigation and Preparedness Measures

The Port and Harbour Bureau engineers did have some limited emergency preparedness procedures in place prior to the earthquake. However, this scale of earthquake had not been predicted for the Kobe area and the plans developed were insufficient to cope with the size of the disaster and the widespread extent of damage.

The Port was well protected for typhoon damage with extensive breakwaters built out into the harbour.

The Port was able to assess quickly the extent of damage and communicate this promptly to its customers to enable them to organise diversion of shipping away from the affected wharf areas. A regular communication sheet in languages other than

Japanese was widely and regularly distributed to publicise the state of reconstruction of the Port area.

#### 6.4 Response and Recovery Aspects

The extent of recovery from the earthquake in eight months has been most impressive. Initially the emphasis was placed on making temporary repairs to enable cargo to flow across the wharves, without repositioning or carrying out any long term strengthening of the key structural elements. Arrangements for permanent repairs were also made and Figure 1.6.1 illustrates the two different permanent repair methods proposed for the repair of rotated caissons within the container handling wharves.

The following methods have been adopted for the repair of the face of the berths:

- Temporary repairs have been carried out at some berths by leaving rotated caissons where they finished up after the earthquake and reconstructing the pavement behind.
- Figure 6.1 shows the long term repair methods where sufficient room is available within the harbour area to extend the wharf face beyond the line of the previous berth face. This is being achieved by one of two different construction methods:
  1. The placing of a new line of caissons outside of the existing damaged face. The new caissons will be mounted to resist higher lateral loadings from the reclamation (Figure 6.1a).
  2. The driving of piles beyond the rotated caisson to create a new wharf structure in front (Figure 6.1b).
- The final alternative for areas where the wharf face cannot be moved outwards is to lift the old caisson clear, excavate and rebuild the foundation and reseat it near to its previous position in a manner which is more resistant to the lateral earthquake loads.

Heavy lifting plant brought into Kobe from elsewhere in Japan is making a fast recovery feasible. The use of heavy lift floating cranes of sufficient reach to lift entire container cranes has meant that the cranes do not need to be completely dismantled. There are still several cranes sitting with their superstructure on the deck awaiting the reconstruction of their supporting legs. Of the 55 cranes damaged, 26 cranes were operational as at 26 August 1995 with 10 container berths open for use. As of that day there were a total of 86 of the original 239 berths available for use and this was meeting up to 70% of the number of liner trades which had been operating through the port prior to the earthquake.

Shippers have redirected some vessels to other ports such as Osaka and Yokohama and some of the Kobe port workers had moved to these ports to cope with the extra traffic through these ports.

Price reductions through the Port of Kobe have been offered to users of damaged facilities to compensate for disruption. These reductions will remain in place until March 1996 or until a facility is fully restored. Cost estimates provided in fact sheets issued by the Port of Kobe show that all existing port facilities will be completely restored within two years of the earthquake at a cost estimated at NZ\$10 billion. An amount of NZ\$16 billion is also set down to be spent on additional port development over a ten year period. (Costs for reconstruction of private port facilities are additional to these figures, although

an allowance of NZ\$0.33 billion has been included in these figures for the reconstruction of damaged seawalls).

#### 6.5 Interdependence Issues

The inability of the port area to operate without power and water has been emphasised by this earthquake. Power was restored relatively quickly to enable refrigerated cargoes to be saved, although in the heat of summer more losses would have resulted.

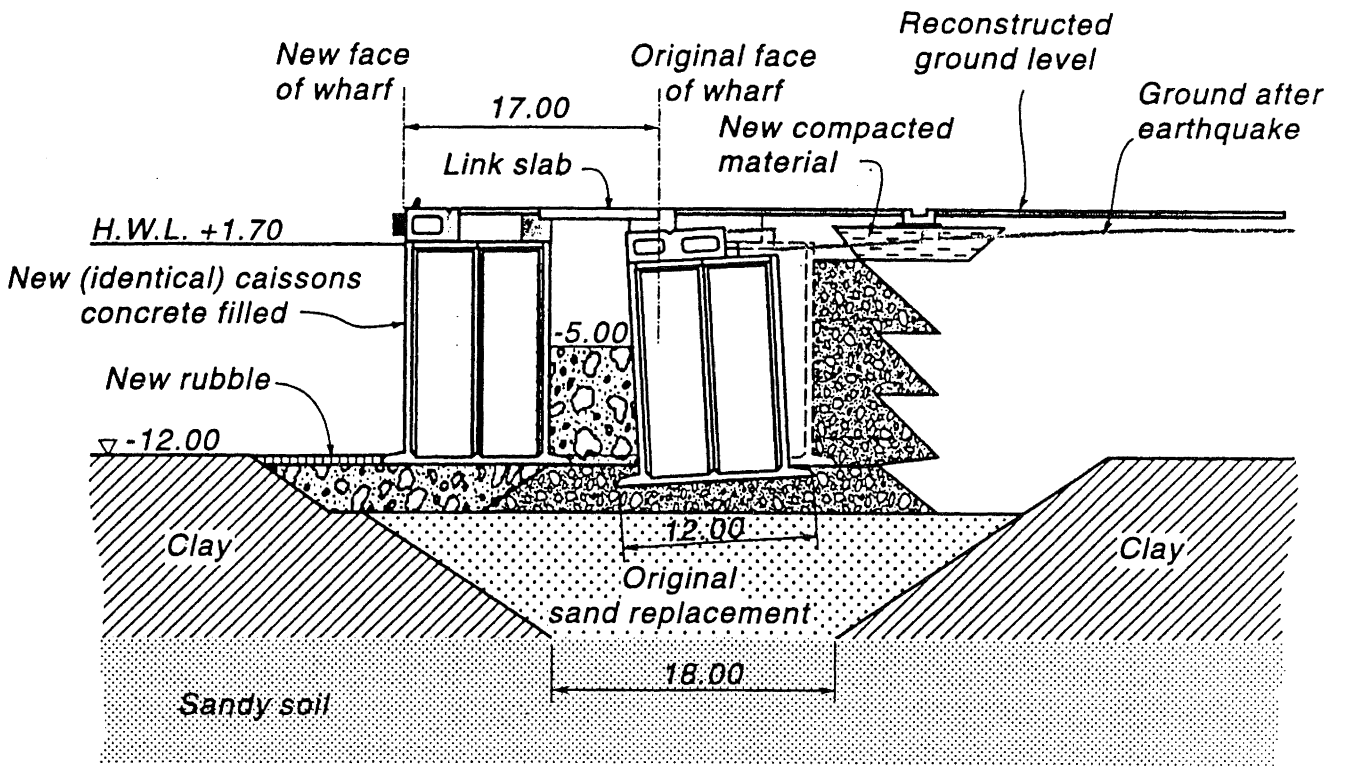
The Port is still constrained by the delays to traffic within the city area. This is caused by the extensive reconstruction of the roading network. While container trucks are getting priority access through the city area, the congestion does result in long delays for the truck operators. Twenty-four hour seven day a week operation of the Port has been brought in to attempt to alleviate this problem and to ease pressure on the available berthage.

The need for the reinstatement of the damaged link between Kobe Route 3 and the Port Island wharves was essential. This need was such that the Port of Kobe required the construction of a temporary bridge while the damaged link remains under repair. This multi-span bridge was completed in August, and has been designed and constructed at some cost to a high standard.

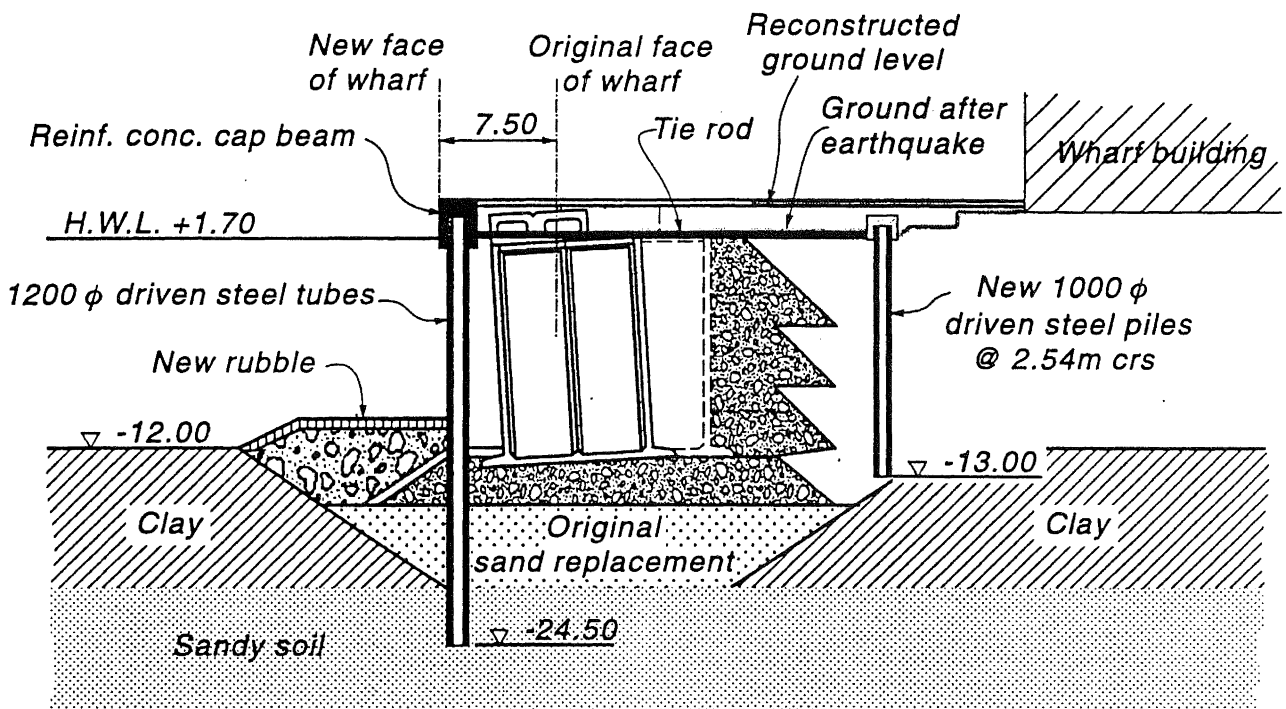
The reclamations underway for port development have meant that the disposal of demolition waste from demolished city buildings can be used as fill material. Part of the reclamation on Port Island is also being utilised for emergency housing. Thus, as well as forming a vital route in for relief and construction supplies, the Port is meeting a social need in the reconstruction of the remainder of the adjacent city area.

#### 6.6 Lessons for New Zealand

- Well engineered port structures can be made to withstand earthquake loadings of the magnitude experienced in Kobe. The extra costs in designing to these loadings is likely to be small in comparison to the reinstatement cost for any failure and the inconvenience of being without the port infrastructure during the repair period.
- Many port areas are on reclaimed land. Settlement and/or liquefaction of these areas is likely during an earthquake and allowance should be made for this in services where they transfer from reclamation to a rigid piled structure. Retaining structures do need to be designed to withstand the earthquake loading from land behind with a considerable safety margin if damage is to be avoided.
- Use of materials which can flex with earthquake movement is important for services within reclaimed areas.
- Port areas are very reliant on good transport routes to the areas they serve. If these are disrupted the resulting congestion is likely to divert trade to alternative ports unless the loss can be compensated for to those affected.
- The port area has a vital role in assisting with the recovery through the delivery of heavy equipment, emergency water supplies and materials to aid with the initial recovery and the reconstruction.



(a) Placement of New Caissons



(b) Driving of Steel Piles

FIGURE 6.1 Repair methods for rotated sea wall caissons

- The reconstruction is made much easier and quicker by the availability of heavy lifting and reconstruction plant close at hand. This plant is required for the large civil engineering projects undertaken regularly in Japan. Many large floating cranes are now in the Kobe area to assist with this reconstruction.

## 7 GAS SUPPLY

### 7.1 Network Description

Gas supply is 94% LNG which is imported under long-term contracts from Brunei, Australia, Indonesia and Malaysia. The remaining 6% is Petroleum Gas (from Naptha) which is basically maintained as an emergency backup to LNG.

The Gas sales segment split is:

	<u>By Volume</u>	<u>By Number</u>
Residential	40%	95.5%
Industrial	42%	0.4%
Commercial	18%	4.1%

The average residential user uses 19 GJ/year and gas is the dominant energy source for cooking, heating and hot water in the home.

Natural gas from the LNG terminals is transported through high pressure welded steel transmission pipelines which operate at pressures of up to 40 bar. These transmission lines take natural gas to 19 supply stations which are distributed throughout the supply area. At the supply stations, the pressure is decreased and fed into a medium pressure pipeline network. The medium pressure networks are divided into two pressure ranges known as medium pressure A (3 to 10 bar) and medium pressure B (1 to 3 bar operating pressure).

Both medium pressure A and B pipeline networks are used in inter-city transportation and in gas supply to large hospitals, hotels, factories and other institutions. A total of 37 large diameter spherical gas holders are located at the various supply stations and these provide a buffer for the daily fluctuation in gas demand.

The gas is then reduced to low pressure (1.0 - 2.5 kPa) for distribution to households and small to medium industrial and commercial customers. The medium pressure mains are either welded steel (87%) or ductile iron pipes (13%), and are consequently reasonably resistant to damage by earthquake. The low pressure distribution mains comprise steel pipes (61%), ductile iron pipes (30%), grey cast iron (6%) and polyethylene PE (3%). Only a small amount of the low pressure steel system is welded, with most of the low pressure steel pipes being either screwed or mechanically jointed. Together with the older cast iron pipes, these proved to be the most vulnerable part of the system during the earthquake.

Distribution mains with pipe diameters of 100mm or greater are buried at a depth of 1.2 metres. Those mains less than 100mm in diameter which are commonly referred to as branch pipes are buried at a depth of 0.6 to 0.8m. Because of the possibility of third party damage, current regulations only allow the use of PE pipe for low pressure systems.

The entire gas distribution area of Osaka Gas is divided into several blocks which can be isolated independently from each

other in the event of an emergency. The whole service area is divided into 8 "super blocks" and these are further subdivided into 55 "middle blocks". Only gas supplies to the 8 super blocks can be remotely controlled.

Since the distribution system was relatively recently converted from manufactured gas to natural gas many of the sector valves from the conversion still remain in place and were able to be used for isolation. However because Osaka Gas supplies 5.6 million customers, isolation of each of the middle blocks usually resulted in suspension of supply to greater than 100,000 customers.

### 7.2 Damage Assessment Report

Damage to the network and production facilities can be summarised as follows:

#### *Production Facilities*

Major production facilities at LNG terminals at Senboku (further east round Osaka Bay from Kobe) and Himeji (west of Kobe) were not affected by the earthquake, and although they were not in operation at the time, automatic terminal shutdown would have occurred if an earthquake of seismic intensity greater than four on the JMA scale (MM VI) had been detected. At Senboku terminal, which is on reclaimed land, site liquefaction occurred over 9,000m<sup>2</sup> (1% of site area) where the ground had not been compacted. However damage was limited to inclined instrumentation boxes and water leakages through flanges of a seawater line.

Even though a maximum ground acceleration of 0.833g was recorded at Fukiai supply station, no damage was sustained by the two gas holders at this site. A total of 12 gas holders were located near the epicentre and none experienced damage. None of the 3,212 governor stations installed in the Osaka Gas service area were damaged.

#### *High Pressure Pipelines*

The high pressure pipeline network (total length 490km) sustained no damage even in areas along Osaka Bay where sand boil, fissure and ground subsidence occurred due to liquefaction.

#### *Medium Pressure Pipelines*

The medium pressure A & B pipelines sustained failure at a total of 106 locations (see Table 7.1) and most of the leakage was due to loosened dresser couplings caused by the resultant ground movement. A total of 14 leaks were found on welded steel pipes due to weld cracking because of a low grade welding process. Most of the leakage at dresser couplings occurred at areas of ground liquefaction and where seismic intensity was greater than JMA 7 (MM XI), and in particular where dresser couplings were used in valve manholes. Dresser couplings used on direct buried steel pipes had in many cases been covered with a sleeve which had then been welded to the pipeline, and in such cases leakage had not been a problem.

#### *Low Pressure Pipelines*

The majority of the leakage from the distribution network occurred on the low pressure pipelines, as indicated in Table 7.2. It can be seen from Table 7.3 that the majority of failures occurred at screw threads on customer service pipes or at threads on main pipes less than 100 mm diameter.

Table 7.1: Number of Failures of Medium Pressure Lines by Type of Pipe

	Steel Pipe					Cast iron pipe				Total for joints	Total for pipe bodies	TOTAL
	Weld joint	Flange joint	Mechanical joint (dresser)	Sub total	Pipe body	Mechanical joint		Sub Total	Pipe body			
						GM II	Bell and Spigot					
Medium A Pressure	8	5	22	35	0	-	-	-	-	35	0	35
Medium B Pressure	6	17	38	61	0	3	7	10	0	71	0	71
<b>TOTAL</b>	<b>14</b>	<b>22</b>	<b>60</b>	<b>96</b>	<b>0</b>	<b>3</b>	<b>7</b>	<b>10</b>	<b>0</b>	<b>106</b>	<b>0</b>	<b>106</b>

Table 7.2: Damage to Distribution System

	Medium Pressure			Low Pressure				TOTAL
	MP-A	MP-B	Total	Main (>100mm)	Branch (<100mm)	S.P.	Total	
Joint Part (Inc. Welding)	35	71	106	549	4,609	6,184	11,340	11,446
Pipe Body	0	0	0	34	0	0	34	34
<b>TOTAL</b>	<b>35</b>	<b>71</b>	<b>106</b>	<b>583</b>	<b>4,609</b>	<b>6,184</b>	<b>11,374</b>	<b>11,480</b>

Pressure Categories: M.P. - A:Medium Pressure A system (3-10 bar)

M.P. - B:Medium Pressure B system (1-3 bar)

Low pressure system: 100-250mm H<sub>2</sub>O

Table 7.3: Number of Failures of Low Pressure Lines by Type of Pipe

	Steel pipe						Cast iron pipe					PE	Steel pipe		Total for joints	Total for pipe bodies	GRAND TOTAL
	Welded	Flange	SGM	Screw	Sub total	Pipe body	GM11	Bell and Spigot type	Socket type	Sub total	Pipe body		Joint	Pipe body			
Main	0	-	-	-	0	0	76	439	34	549	34	0	-	-	549	34	583
Branch	-	-	156	4451	4607	0	-	-	-	-	-	0	-	-	4607	0	4607
Service pipe	-	-	106	6045	6151	0	5	28	-	33	0	0	-	-	6184	0	6184
Service pipe on customer's property	0	0	59	3906	3965	0	3	7	0	10	2	0	-	-	3975	2	3977
House pipe between meter and cock	0	0	13	11098	11111	0	1	1	0	2	0	0	8	0	11113	0	11113
<b>TOTAL</b>	<b>0</b>	<b>0</b>	<b>334</b>	<b>25500</b>	<b>25834</b>	<b>0</b>	<b>85</b>	<b>475</b>	<b>34</b>	<b>594</b>	<b>36</b>	<b>0</b>	<b>8</b>	<b>0</b>	<b>26436</b>	<b>36</b>	<b>26472</b>

This is not unexpected as threading is the preferred method of jointing on these smaller pipe sizes, and the joints then become the weakest part of the network. Osaka Gas had developed a compression type joint with an end loading arrangement to anchor and join smaller diameter steel pipes. These joints prevent slip out, are highly earthquake resistant and are known as the SGM joint. These SGM joints were used for repair and restoration of the damaged sections of the low pressure steel pipelines.

There were no reports of any failures from a total length of polyethylene pipe of 1169 kms.

The disaster mainly affected residential customers together with some commercial users. No large industrial customers were severely affected and, generally speaking, users of any size were not in a position to use gas immediately after the earthquake, even if it were available.

### 7.3 Effectiveness of Mitigation and Preparedness Measures

The overall performance of the distribution network and production facilities during the earthquake was enhanced by the fact that Osaka Gas had recognised that earthquakes were a distinct possibility, and had implemented various measures to reduce the possibility of damage. These included the construction of earthquake resistant LNG storage and distribution facilities and the introduction of micro computer controlled intelligent gas meters. Production facilities and gas holders are designed to conform with relevant legal requirements, and are constructed after confirming their earthquake resistant performance by means of dynamic structural analysis and other advanced techniques.

Osaka Gas had also been strengthening parts of the pipeline network to make them more resilient by using earthquake resistant joints for joining pipe (particularly in areas of public assembly and locations of known subsidence such as reclaimed land). Gas meters for domestic customers have been replaced with intelligent meters that shut off the gas flow when a seismic sensor detects an earthquake, and currently 70% of domestic customers have intelligent meters installed.

### 7.4 Response and Recovery

The initial response following the earthquake is summarised as follows:

05:46	Earthquake occurred.
05:52	Seismic Intensity of 5 (MM VII) or more was identified.
11:50	Suspension of gas supply to Kobe Blocks 2 and 3 with 386,000 customers.
16:30	Suspension of North Osaka Block 7 with 101,000 customers.
19:30	Suspension to Kobe Block 1 with 221,000 customers.
21:00	Suspension to Kobe Block 4 with 124,000 customers.

In other areas, gas supply to a further 23,000 customers was also suspended, giving a total of 855,000 customers suspended.

As the above summary shows, some 6 hours elapsed before Osaka Gas acted and began shutting off supply. While the company was severely criticised in some quarters for taking this long to act, they had immense difficulty in establishing the extent of the damage, in mobilising staff and in actually reaching and operating manual shut off valves. This is despite having:

- a sophisticated scada and monitoring system
- a well designed system in terms of supply discontinuation
- a well prepared response plan
- an independent, earthquake proof radio communication system
- annual emergency drills

Some of the initiatives that Osaka Gas took in dealing with the residents of areas where gas supply was suspended included:

- they set up telephone hotlines and manned them around the clock so that customers were able to relatively easily obtain information on the restoration and reconnection situation.
- they provided, free of charge, around 170,000 portable LPG cookers to those customers in the worst hit areas.
- they set up temporary shower facilities at shelters and temporary baths at their own bases for use by local residents. These facilities were used for in excess of 90,000 man hours.

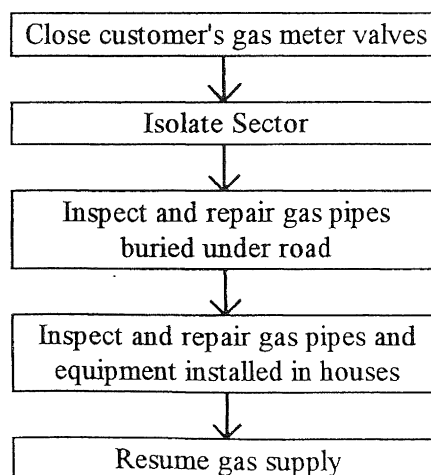
Key aspects in managing the recovery phase were:

- provide clear, frequent and ongoing communication as to what is happening and what progress is being made.
- ensure essential services have supply by whatever means necessary.

The first week after the quake was occupied with damage assessment and resumption of gas supply to vital locations via the medium pressure lines. During these critical days rescue works had greatest priority and gas supply (or alternative supplies) was restored to hospitals, nursing homes, schools, kindergartens and a crematorium. Also some important customers, normally supplied from the low pressure system, got a temporary supply from the medium pressure system via a regulator.

The restoration of the low pressure network commenced on 23 January with the logistics of the operation being a massive management project in itself. Osaka Gas established up to 12 temporary bases at accessible locations ringing the damaged area. Most of the bulk material was shipped by boat or helicopter to the bases where it was stored.

The approach taken with restoration was to begin work in the less affected areas on the perimeter and gradually work inwards to the most seriously affected areas. A set procedure was followed in all cases with safety being of utmost priority, as follows:



First, Osaka Gas personnel visited every customer in a particular area and closed the customer's gas meter cock. Then the mains connection was cut off to form a block (called a restoration sector) of a size from three to four thousand customers. Upon establishing the restoration sector, the mains and branches of each sector were inspected and, in the case of leakage, repaired. If water and/or sand were found to have entered the pipe it was cleaned and discharged. Water ingress was a major problem due to a combination of the very low pressures in the branch and service lines and the common occurrence of water pipe leaks.

After repairing the mains, personnel contacted every customer in the sector and inspected the gas facilities inside the premise (i.e. piping, appliances, air intake and ventilation system etc). Once this occurred for every house in the sector, supply of gas was resumed. This process was repeated for every restoration sector.

In total, restoration involved 9700 people and 4800 vehicles. Of these, 3700 people and 2000 vehicles were contributed by the various other gas utility companies under the auspices of the Japan Gas Association.

The restoration works were carried out by dividing the five middle blocks, where the gas supply was suspended, into over 220 restoration sectors. Restoration of a sector was normally completed in four days but in the worst hit areas much time and labour was taken up in removing large quantities of water and sand/mud which had entered the system. In these areas it often took well over a week to restore one sector. Restoration efforts were also impeded by wrecked houses which blocked roads.

Despite the problems, restoration works were essentially completed on April 11 (i.e. a period of 85 days, refer Figure 2.4) with supply having been restored to over 700,000 customers in the intervening period. The total cost of the earthquake to Osaka Gas was estimated to be NZ\$3.2 billion.

### 7.5 Interdependence Issues

The greatest problem was the communication within the first hours after the earthquake. The cellphone network was overloaded within one hour, as soon as people headed to work. The company's own radio communication system was not affected by the earthquake and was invaluable for information transfer between the offices and field crews.

Many of Osaka Gas' employees were living in other cities within the greater Osaka region and depending on trains to commute to work. With most of the trains being out of operation, commuting from home to work became a major problem. The restoration teams had to start work very early in the morning in order to avoid traffic congestion.

The availability of electricity was not critical for the gas company, as repair crews were mobile and had their own energy supplies. Some criticism was expressed for a lack of communication between Osaka Gas and Kansai Electricity during the first hours and days after the quake, when some gas leaks were ignited by restored electricity.

Accommodation as close as possible to the damaged area had to be found for the 3,700 gas workers coming from other parts of Japan. This was an additional demand on an already overstretched supply of temporary housing in the area. Some ships were used as hostels, and other workers were accommodated in hotels that had suffered only minor damage.

Because the damaged piping was large in diameter and made from cast iron or steel, much of the material was bulky and heavy, and had to be transported by sea. Many of the harbour facilities however were damaged and could not be used. Small goods such as food boxes were often unloaded by hand. Another problem was too little space for storage of equipment, tools, vehicles and removed rubble.

Those lifeline facilities which depended on gas, such as hospital, schools, nursing homes and a crematorium were reconnected within a week. These institutions were either supplied from the medium pressure system which had only little damage or got a temporary supply with LPG, CNG or LNG.

Other interdependence issues included:

- Broken water mains allowed water to enter damaged gas lines.
- Road and footpath excavation for gas repairs hindered surface restoration.

### 7.6 Lessons for New Zealand

As a result of this visit it is very clear that the larger the earthquake and the larger the population centre affected, the longer will be the period of disruption. Although New Zealand does not have the same degree of population density, there are several lessons that can be learnt from the Great Hanshin earthquake. The following recommendations are suggested to minimise damage and disruption both to gas networks and to customer relations in the event of a similar earthquake occurring in New Zealand.

#### ● Rehabilitate Old Networks

Continue with and, if possible, accelerate the rehabilitation program to replace in particular screwed steel, old cast iron and asbestos mains with polyethylene.

#### ● Investigate Vulnerability

Examine the network in detail for areas of vulnerability, particularly in areas prone to earthquake and/or close to known fault zones. Buildings and bridges designed and constructed according to modern seismic standards in general survived the earthquake well. However, older buildings are prone to collapse and damage to meters and pipework will occur. Consideration should be given to identifying the risk associated with these buildings and how the gas supply can be isolated with minimum disruption to other customers when access to the site is restricted.

All pipework on older bridges should be subject to risk assessment and appropriate action taken.

#### ● Review Emergency Plans

Emergency plans should be reviewed regularly and tested by way of regular emergency exercises.

Communication with other service utilities is important. Several fires were caused because the local electricity company did not liaise with Osaka Gas before restoring power to an area.

Communication within the gas industry is very important, because with a reducing workforce of skilled people, dependency on each other is likely to be significant.

### • Investigate Intelligent Meters

These meters contain a seismic sensor that shuts off gas flow if a tremor occurs that is in excess of a pre-set limit. They cost about NZ\$300 and have batteries that last 10 years. The use of these meters or other automatic shut off devices should be investigated. They could, for example, be made available as an optional extra for concerned customers.

### • Sectorise Networks

The importance of sectorising the network in order to be able to shut off damaged portions and maintain supply to undamaged areas cannot be over-emphasised. All utilities should examine the flexibility that is available in their systems.

### • Communication

In the event of a disaster like this good communication is vital. Good relations with the media, particularly TV, must be developed. The establishment of a media plan for the industry could be considered. A plan to provide alternative supplies (ie CNG, LPG) to key customers could also be developed.

### • Expect the Unexpected

Prior to January, 1995 Kobe was regarded **NOT** to be prone to earthquake; an opinion which was obviously ill-founded. While factors such as lower housing density, better building standards and a higher proportion of polyethylene mains will mitigate earthquake damage in NZ, everything possible should be done to be prepared and regard all areas as potential earthquake sites.

## 8 ELECTRICAL NETWORKS

### 8.1 Network Description

Kansai Electric Power Company, with 11.7 million customers and a system peak load of 28,000 MW, is the second largest utility of the nine generating, transmission and distribution utilities in Japan. The company transmits electricity at a number of voltage levels from 500 kV, through 275 kV, 187 kV, 154 kV to 77 kV.

Kansai Electric has a total of 1271 sub stations of which 67 were within the earthquake affected areas.

Local distribution in the Kobe area is principally by low voltage (100 volt household supply) and high voltage overhead lines. These are supported on concrete poles, with only limited underground cabling in the central business district.

All Japanese utilities have adopted the same earthquake design standard since 1980. This requires the qualification of all equipment to survive an earthquake with a 0.3g ground acceleration. All equipment is shown to be adequate by a sine beat shaking table test.

By comparison, Trans Power uses a 0.4g ground acceleration spectra modified to 0.7g near faults. Equipment can be proven adequate by either test or analysis. If analysis is used, conservative safety factors are imposed to cover uncertainty in modelling.

### 8.2 Damage Assessment Report

No functional damage was caused to the 500 kV facilities which represent the backbone of the Kansai power system. All of the 500 kV network is located outside the peak ground shaking area. There was however substantial damage to the 275 kV and lower voltage facilities [Morii, 1995].

#### *Generation Facilities*

Ten of the 63 available thermal power plant units were damaged. This damage typically involved distortion of the boiler tubes.

#### *Sub stations*

Of the 67 sub stations in the earthquake area, 48 sub stations sustained some damage and 8 were blacked out completely. Three of the four 275 kV sub stations in the Kobe area were blacked out. 14 out of the 29 (48%) transformer sub stations within the highest intensity zone were damaged. These 14 were all constructed prior to 1965, while the seven sub stations built after 1975 were undamaged.

Sub station damage featured the following:

- Lightning arrestors and disconnectors either destroyed or badly misaligned (Figure 8.1).
- Centre-clamped bushings on 8 older oil circuit breakers slid across the baseplate resulting in oil leakages.
- Anchor bolt failures to 17 transformers resulting in transformer movement and consequent destruction of attached equipment
- Secondary bushings on some transformers broken

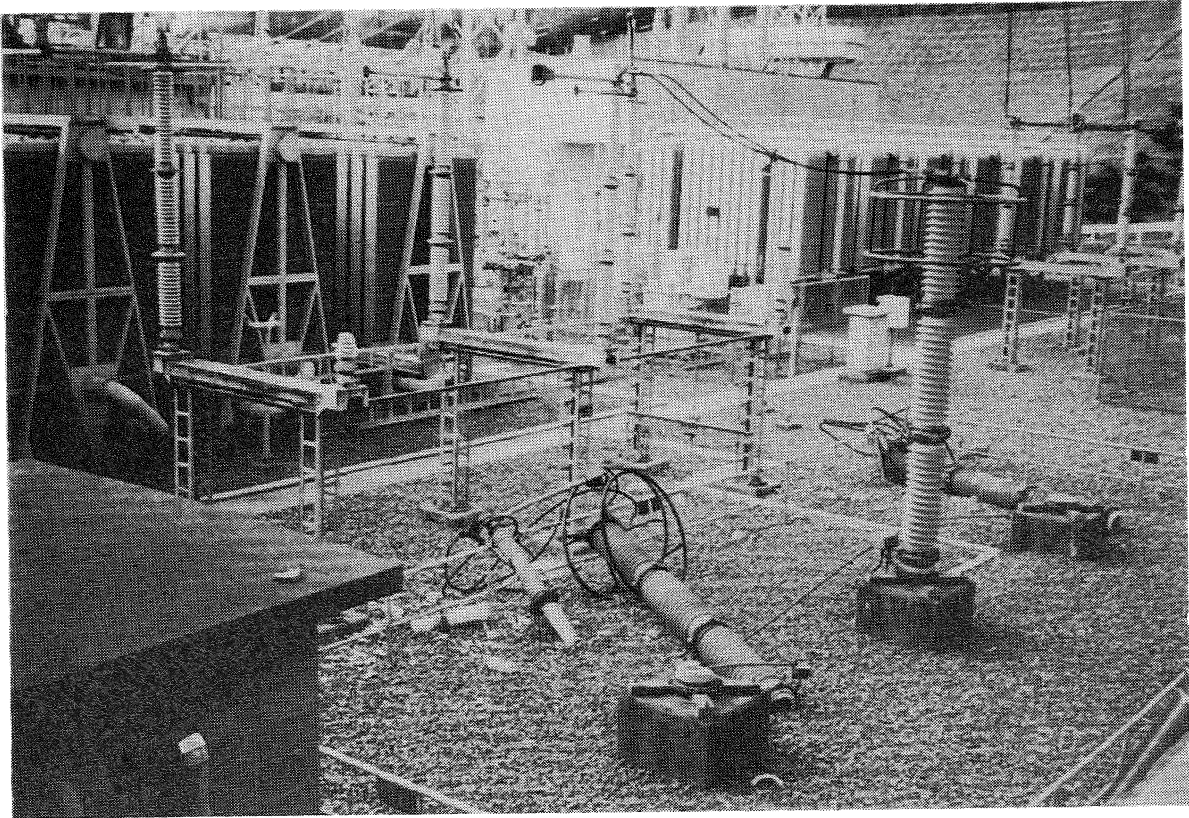
#### *Transmission Lines*

Twenty five transmission lines sustained damage, including the following:

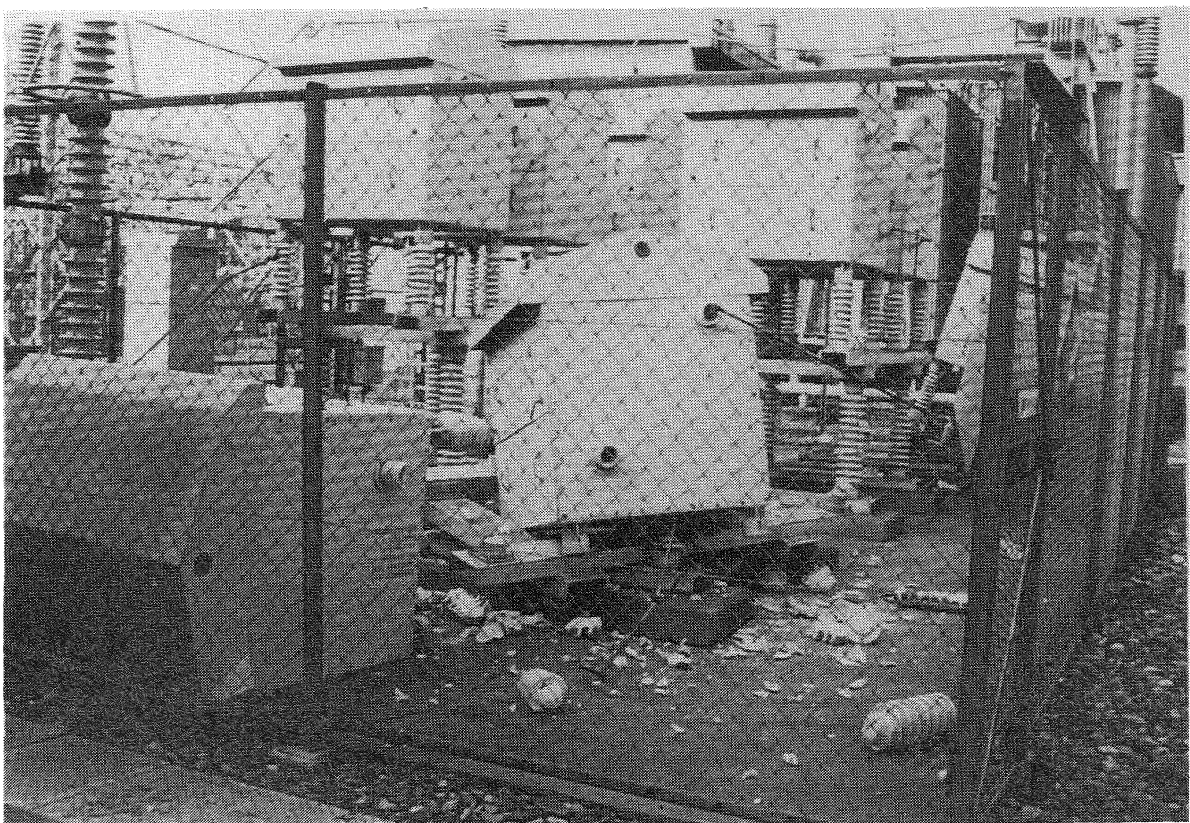
- Jumper insulators on strain towers failed. Most jumper insulators are long rods rigidly bolted to the tower in contrast to Trans Power practice of using disc insulator jumpers.
- Tower steel member distortion on twenty towers resulted in excessive crossarm deflections and electrical failures. This appears to have principally occurred due to movement of tower foundations in areas of very high ground displacement, rather than direct failure of steel members.
- Damage to underground transmission lines was found along 95 lines. The greatest damage was concentrated in areas subject to strong earthquake movement along the waterfront.

#### *Distribution Lines*

A total of 649 circuits were damaged due to failure of distribution lines. Many distribution poles carried either pole-mounted transformers or SFL gas switches, and are consequently top heavy. Approximately 8000 distribution poles fell over or were broken when buildings collapsed.



*FIGURE 8.1 Collapse of a 275 kV arrester*



*FIGURE 8.2 Collapse of a neutral resistor*

Distribution transformers were subject to tilting and deformations from ground distortion.

Underground ducts through which distribution cables run suffered various degrees of damage, including the collapse of the side walls.

### 8.3 Effectiveness of Mitigation and Preparedness Measures

Following the 1978 Off-Miyagi earthquake, there has been a considerable mitigation effort put in to reduce the effects of earthquake motion, including stringent design standards for new equipment.

However, at a system level the design of the network has also embodied the following key features:

- Redundancy and flexibility - a strongly interconnected grid.
- Diversity of equipment types.

A key preparedness measure was participation in a nationwide mutual aid scheme to provide assistance to/ receive from other electric power companies.

The importance of these measures are elaborated upon in the following section.

### 8.4 Response and Recovery Aspects

Loss of power to 2.6 million households occurred at the time of the earthquake. This figure represents approximately 25% of the total number of customers.

Switching operations were immediately performed to re-route electricity via unaffected sections of the distribution network (i.e. 77 kV). Within two hours, the number of households without power was reduced to 1 million.

Within 8 hours, 50% of lost power was restored, and within three days 90% of power was restored. Full restoration was achieved in seven days (refer Figure 2.4). In comparison, in Los Angeles 90% power restoration was completed within 20 hours of the Northridge earthquake.

Six 275 kV sub stations and two 154 kV sub stations were completely blacked out after the earthquake. Despite equipment damage and substation blackout, the system was quickly relivened by bypassing damaged equipment. This was enabled by the strong and well gridded network in the area, and the multiple interconnections between the various voltage levels permitting complete damaged sections of sub stations to be duplicated by a lower voltage equivalent.

The system load was reduced to 60% of the monthly average demand by the estimated total loss of 50,000 of the 1 million customers in the area. The demand was subsequently increased to 80% of the monthly demand as people swapped away from gas cooking to electricity. The demand could be met due to system redundancy, despite damage to equipment.

#### Personnel for recovery works

Immediately after the earthquake, the company modified its entire organisational structure in order to assign as many staff as possible to the task of restoring power supplies. This task was made more complicated because a number of service centres were located in the areas worst affected by the earthquake, and sustained damage.

Only 45% and 55% of staff were able to get to the Osaka and Kobe offices respectively on the day of the earthquake. The company allocated more workers on a step-by-step basis, as the assessment of damage proceeded and the restoration work entered new stages. Figure 8.3 illustrates the source of workers during the emergency power distribution stage. Other electric power companies in Japan provided an additional 319 personnel.

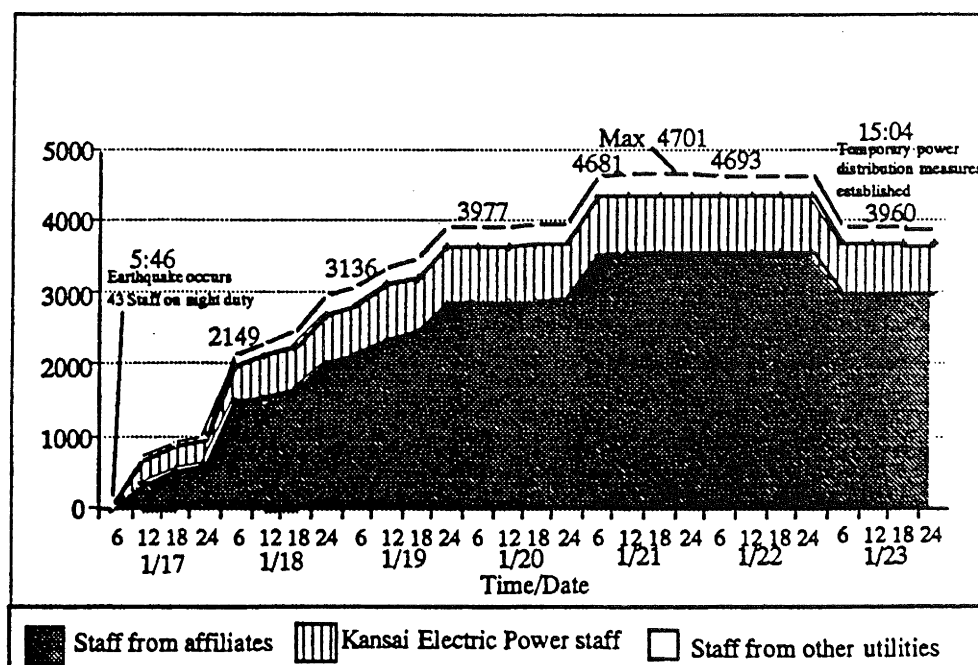


FIGURE 8.3 Deployment of Staff During the Emergency Power Distribution Stage

It is understood that the "staff from affiliates" shown in Figure 8.3 refers to contract staff who carry out everyday tasks for Kansai Electric Power Company. This available regional resource base, particularly in proportion to Kansai Electric Power staff is highly impressive, and was a key factor in the rapid recovery of service.

#### *Procurement of materials and equipment*

Kansai purchased the majority of electrical equipment from one supplier in the local area. As this supplier was out of action due to earthquake damage, some replacement equipment was unavailable. The company made use of other materials that had been stored for emergency use. To restore damaged facilities quickly and safely, the company provided the affected service centres not only with workers but also with as many special purpose vehicles as possible. Since the earthquake caused extensive damage to support structures, the company provided a large number of special vehicles for aerial work (cranes), and excavation and erection of poles.

In addition to the additional personnel noted above, the other Japanese power companies provided diverse types of material assistance including 52 high-voltage power generation vehicles and 77 working vehicles and vehicles equipped with satellite communications facilities.

The loan of the power generation vehicles was particularly important, as Kansai Electric Power only had eight such vehicles.

The power generation vehicles were used to provide electricity to vital service facilities such as police and fire stations, hospitals and community shelters. Other facilities to receive power from these vehicles included hotels, camping grounds and the company's own facilities.

#### *Food and temporary accommodation*

After the earthquake the company undertook to transport food and drink and other necessities for workers to the affected areas from two different sources - from the head office and from the Himeji branch office. On the day of the quake, however, traffic in Kobe and surrounding areas was heavily congested - much worse than expected - and this caused delays in delivery of these provisions. In some places on that day, staff had to make do with dry biscuits and other emergency food kept in stock. From the next day on, however, conditions improved with earlier departures of delivery vehicles and the use of sea transportation where possible.

Since most hostels, hotels, and other private accommodation were closed in the affected areas, the company used meeting rooms and other available space in its service centres as temporary overnight accommodation. In addition, for extra accommodation capacity, the company also made use of passenger ferries, long-distance sightseeing buses with toilets, and tents.

#### *Principles and Strategies Adopted for Emergency Power Distribution*

The following key principles and strategies were adopted in establishing emergency power supplies:

- In allocation of emergency power supplies, the highest priority must be given to vital services (hospitals, shelters,

municipal offices, etc.), and to providing temporary power supplies for refugees.

- Emergency power distribution measures requiring the minimum amount of labour to implement were used, as well as the maximum number of available workers; also as many vehicles as possible were used for maximum mobility.
- Impose strict safety standards in relation to equipment, personnel, and electricity, in order to avoid secondary hazards.

The nature and scope of temporary repairs implemented in accordance with these strategies is diagrammatically represented in Figure 8.4. Emphasis was placed on repair methods requiring the least amount of labour.

The result was the supply of power to all customers able to receive electricity by 3pm on 23 January.

#### *Communications*

One of the key factors contributing to the rapid restoration of power supply was that the private microwave communications system operated by Kansai Electric Power was not damaged.

This microwave system links the central load dispatching centre with all the main power stations and sub stations. Kansai Electric Power also have an independent telephone system using microwaves and fibre-optic cables. As a consequence, the failure of the public telephone system did not impact on the restoration activities.

Interference did become a problem in the days following the earthquake, and so the company set up temporary radio base stations and assigned a different frequency band to each restoration team.

Communications via portable cellular phones was also effective. For communication between a base station in each block and a service centre, due to traffic congestion, the company made frequent use of motorcycle courier services for faster communication.

Trans Power has a similar communication system, and it is designed to a higher security level than the power system to ensure availability after an earthquake.

#### *Transportation Means*

On roads from branch offices in the peripheral area to service centres in the affected area, the flow of traffic on the day of the earthquake was around 10% of the normal speed (ie. about as slow as walking).

The company had five emergency vehicles in the service area of the Kobe branch office. Combining them with those provided by other branch offices, the company managed to put to use 30 emergency vehicles after the earthquake. They were useful even before traffic was controlled, but they became much more effective after traffic controls were imposed, particularly since these vehicles were permitted to ignore general restrictions. For example, these vehicles were allowed to travel three times as fast as ordinary vehicles.

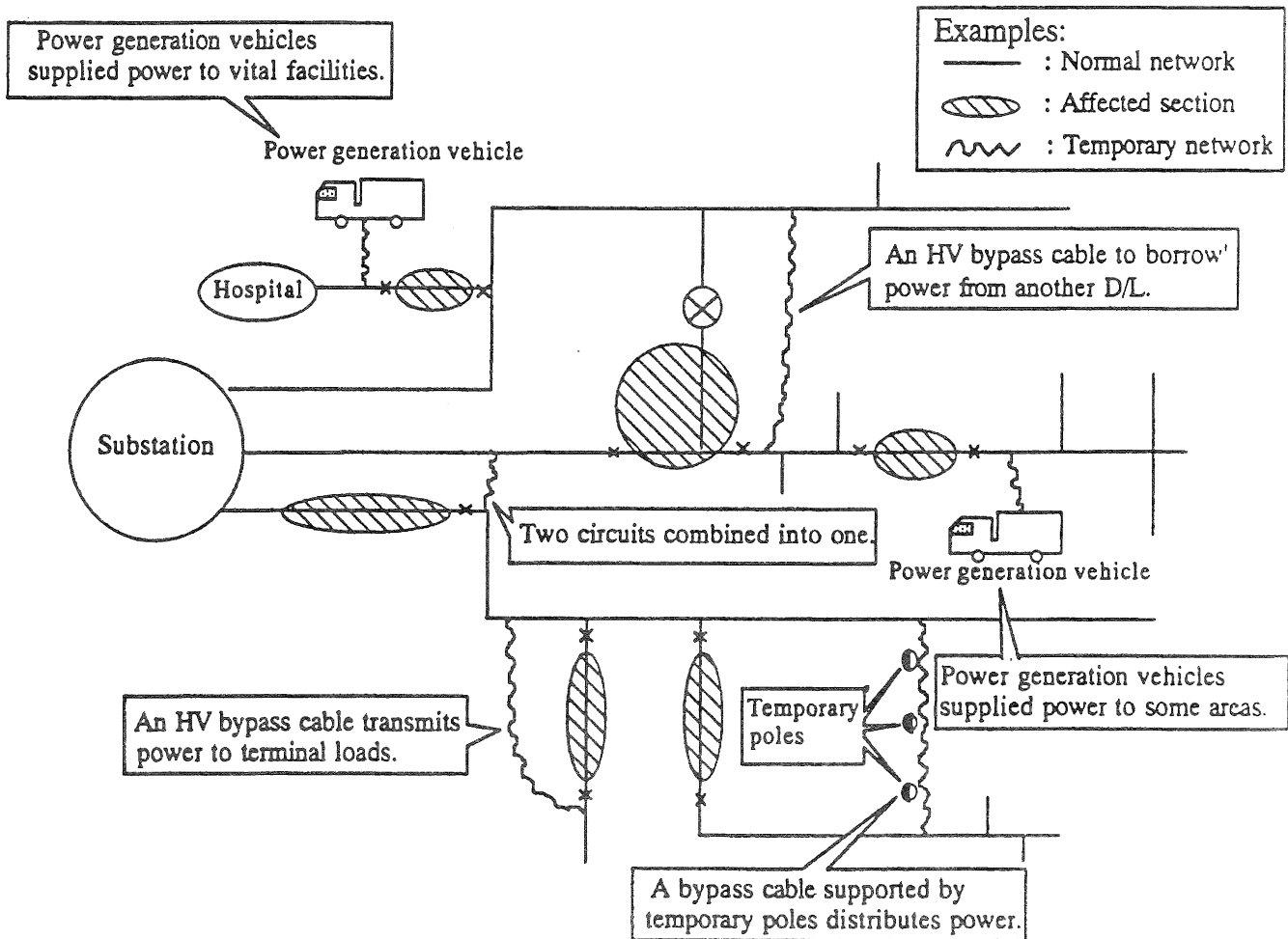


FIGURE 8.4 Temporary Repairs to an HV network

The emergency vehicles were used every day for about a month after the earthquake. They proved especially useful in leading other vehicles employed in restoration work.

#### Subsequent Restoration Work

Following the supply of power to all customers one week after the earthquake via temporary measures, emphasis shifted to permanent repairs. There was a degree of urgency about this work, as the peak demand for electricity occurs in summer due to air conditioning and cooling requirements in 30° C plus conditions.

Work such as repairing segmented routes and replacing damaged underground cables was instigated, along with permanent repairs to equipment and the replacement of damaged poles before the onset of the typhoon season. The process of checking underground cables for damage took four months.

There was also considerable ongoing demand for disconnections and re-connections in relation to damaged and new buildings, along with the wiring of temporary housing camps.

#### Financial Implications

It is estimated that full restoration will cost NZ\$3.8 billion. Approximately 10% of this relates to office building repairs and 30% to repair and replacement of equipment, with the remainder being required for investment in new facilities due to damage from the earthquake.

A NZ\$125 million net loss of revenue occurred in January, February and March 1995. A decrease of 1.6% of total electricity sales for the April 1995 - March 1996 year is predicted. This is due in the main to the number of collapsed and inoperative buildings.

#### 8.5 Interdependence Issues

The response by Kansai Electric Power Company was severely hampered by the congestion in the transportation system. The extensive use of heavily marked emergency vehicles was of some benefit in this regard.

The private microwave system operated by Kansai Electric Power removed what would otherwise have been a critical interdependency.

Some standby generators in emergency institutions were found to depend on reticulated water for cooling, and could not function in the absence of this.

While the process of re-livening power was believed by some to be responsible for igniting buildups of gas, Kansai Electric Power maintained that affected lines were fully checked out prior to re-livening.

### 8.6 Lessons For New Zealand

- The design loads for disconnectors in New Zealand have been increased. Further consideration will be given to the relative merits of seismic testing or more detailed analysis of disconnectors.
- Both at Los Angeles and more so at Kobe, the underlying soils affected the sub station performance. A better understanding of the factors that affect sub station equipment interaction with soils is now possible and will be developed in the near future.
- The Japanese require all new equipment for sub stations to be tested to prove adequate seismic performance, and do not rely on seismic analysis. Trans Power currently permits either analysis or testing to seismically qualify equipment. For major replacement contracts where a significant amount of equipment is to be purchased, testing should be considered. Some advanced work has already been initiated with the University of Auckland, in conjunction with Los Angeles Water and Power, to refine analysis techniques so they may be used with more certainty. Once completed this analysis will be required for smaller orders where testing can be uneconomic.
- A policy to ensure that identical items of critical equipment not be installed in one sub station should be considered. If different brands are installed, then it is unlikely they will all have a similar design defect. There are potential maintenance problems that must be assessed.
- Site specific response plans for particular sites (e.g. sub stations) which identify how equipment can be bypassed and where appropriate spares are located are being developed. In both Los Angeles and Kobe, the systems were restored quickly due to the strongly interconnected grid and the redundancy within the system. Damaged equipment at Kobe was simply bypassed by using alternative voltage levels.

This level of interconnection and redundancy is not present in the New Zealand transmission system and similar response times cannot be expected merely because strong equipment is purchased.

In the absence of system redundancy, quick restoration will be assisted by the development of specific disaster plans for each sub station site which identify how equipment can be bypassed and where appropriate spares or equivalents are located.

Involvement of the connected power companies in compiling these plans will enable the prioritisation of crucial supply circuits.

- Careful co-ordination of the re-livening process with other utilities, particularly gas, as well as the public must be thought through as a part of the response planning process.

## 9 TELECOMMUNICATIONS FACILITIES

### 9.1 Network Description

Telephone services in Japan are provided by a single company, Nippon Telephone and Telegraph Corp. (NTT). NTT owns and operates 85 percent of Japan's cable infrastructure as well as nearly 80 percent of the country's radio services market. The carrier's dominance of Japan's domestic telecommunications network is such that most alternative service providers license and resell network capacity from NTT.

The telephone local access network in the Kobe area consists of a combination of overhead lines and ducted underground cables. Approximately 20% of cables for local calls and 80% of the toll lines are underground.

There are 1.5 million lines in the affected area.

Four companies provide cellular services in the Kansai area.

### 9.2 Damage Assessment Report

On the morning of the earthquake, telecommunication services were disrupted to 285,000 of the 1.5 million lines in the region. Of the 30,000 data circuits and general leased lines 3,170 failed.

Major switching facilities, which carry communication between Prefectures were not damaged.

Major transmission lines were affected in a four block area only. These were switched over to spare transmission lines which substantially reduced the impact on ordinary subscribers.

Communication within the Prefecture were severely impacted by the failure for a number of hours of 11 switch units at 7 sites. These failures caused problems for up to 285,000 subscribers. The cause of these failures was damage to batteries and emergency power generating facilities. Some exchanges failed immediately the earthquake struck and others failed later when battery reserves were exhausted. The power failures also caused links passing through these sites to fail.

While NTT reported damage to three steel towers which were built on the roofs of buildings, the damage was not sufficient to interrupt the radio links using the towers. Three of NTT's network buildings were damaged.

Approximately 3,500 public telephones in the disaster area were disabled, with 1,800 being restored by the 1st of February [Takei and Maki, 1995].

Telephone service congestion occurred on a huge scale. It was estimated to be the largest case of traffic congestion in Japan since entering the information age. The number of calls trying to reach the Kobe area from throughout the country reached almost 50 times normal peak on the day of the earthquake. The next day they still reached 20 times the normal peak. Congestion was compounded by many handsets having been knocked off hook and the concentration of calls to specific emergency organisations immediately after the earthquake. This resulted in many complaints. Normally such congestion would converge quickly but in this case new disaster information was added as time passed and the reported scale of damage expanded day after day. Thus it wasn't until January 22 that the congestion status between Kobe and the rest of the country was finally resolved.

Some specific circuits for emergency calls (119 and 110) stopped operating immediately after the earthquake. Problems increased as time went by as calls to directory assistance, faults and service assignment centres could not be responded to immediately.

Local access links which connect NTT with their customers premises are predominantly provided by aerial cable. These were cut by either building collapse, damaged poles or fire at the subscribers premises. As a result 193,000 subscribers were without service.

Approximately 200,000 lines were recovered within two days, although it took about 2 weeks to fully restore the service. The earthquake caused about NZ\$460 million in damage to NTT's physical plant and cable infrastructure. This figure does not include damage to NTT's Cellular network.

Cellular network damage affected different service providers in different ways. One service provider had two switches, neither of which were damaged by the earthquake. However, 27 of the company's 153 base stations sustained damage that caused site failure [Sextro, 1995]. This damage fell into three categories. At two sites, buildings around the base stations collapsed damaging antennas and other equipment. Twenty base stations ceased operation because their transmission lines between the station and the switching centre were cut. An additional five base stations stopped functioning due to loss of the mains power supply. Sixteen base stations were restored on 17 January and the remainder within 6 days. Call volumes increased 30 fold which caused some overloading of the cellular switching equipment.

A second provider had 37 out of 80 cell sites out of service primarily through loss of mains power. Recovery was rapid and all were restored within 2 days. Failure of a base station did not always prevent communication from the surrounding area as sometimes coverage could be obtained from more distant cell sites. Overload of cellular switches was a major problem.

Underground cables generally suffered minor damage, whereas overhead lines sustained considerable damage. This damage typically resulted from either fire or the collapse of buildings, especially houses.

There is an open cut telephone tunnel with a length of about 2 km in Kobe, and this has an average cover depth of 3m. A maximum movement of 180mm was found at the expansion joint at the section between the telephone exchange centre and the tunnel. A box culvert near the badly damaged Daikai underground railway station had movement at an expansion joint of 40mm horizontally and 130mm vertically. Liquefied sand and water flowed into the culvert at this point. Locations where liquefaction of the ground occurred was found to correspond with one of the hardest hit sections of the open cut tunnel.

The breaking off of metallic conduits, the failure of polyvinyl conduits, and the peeling of cement mortar off the walls near the connections between the conduit and the manhole, was quite widespread. Most of the conduits that had been laid throughout Kobe City were old and provided for no expansion or contraction. The damage by the earthquake was concentrated in those old type conduits.

Approximately 14,000 manholes had been installed, chiefly in the hardest hit areas of Kobe City, Ashiya City, and Nishinomiya City, and about 15% of these suffered some damage from the earthquake. The most common type of

damage was cracks in the neck of the manholes.

NTT uses an underground conduit enclosing communications cables to make connections to subscriber's buildings. In Port Island and Kobe - Sannomiya Area, settlement in the range of 300-500mm in the ground near an approach to some buildings occurred. This movement led to the separation of some of the metallic conduit joints, the breakdown of polyvinyl conduits and the cutting off of some of the communications cables in the approach to the buildings.

The NTT communications cable conduits across waterways are usually fixed to the underside of bridge girders. Joints that allow sufficient expansion or contraction in the event of an earthquake have been recently developed, and it is understood that these new joints suffered no damage from this earthquake. On the other hand, severe damage was done to the joints constructed to earlier specifications that permitted less expansion or contraction. Some of the conduits were damaged by the settlement of an embankment behind a bridge abutment during the earthquake.

Underground cables did not sustain damage that affected the telephone service. There was however widespread relative movement of cables in manholes. Cables fall into two classes: optical fibre cable and the metallic cable made up of copper wire. No significant difference in either of the classes that would have affected the telephone service was found.

### 9.3 Effectiveness of Mitigation and Preparedness Measures

Table 9.1 summarises the history of seismic improvement measures for underground telecommunications facilities in Japan. These measures were initiated in view of the damage caused by some of the strong earthquakes that had occurred in the past. Soon after the Miyagi-Ken Oki Earthquake occurred in 1978, a thorough investigation into the development of the duct sleeve and the seismic conduit joint began. The former is set at the place where conduits and manholes are joined together and permits contraction or expansion of the joint, while the latter is inserted in a conduit run to provide for the expansion or contraction of the conduits and serves to prevent it from becoming separated. In 1982, the application of both of these devices to underground facilities began.

The underground facilities to which these devices had been applied suffered little damage from this earthquake. It has been found that the damage to underground facilities varies in size according to the following three conditions:

- (i) the structure the conduits are made up of;
- (ii) whether the ground becomes liquefied or not;
- (iii) whether or not the facility is located in an earthquake-stricken area with a seismic intensity of 7 or more on the JMA scale (MMX-XII).

There is a significant difference in the amount of damage to underground facilities between the liquefied area with a seismic intensity of JMA 7 and the unliquefied area with a seismic intensity of JMA 6 (MM VIII-IX). The breaking off of conduits joints resulting from ground deformation in a liquefied area is more frequent than in an unliquefied area.

NTT has used stringent building construction control based on the Japan Building Standards Act. While many buildings and highways were reported damaged, NTT buildings received less damage. This was considered a good result and justification of their mitigation measures.

Table 9.1: History of Seismic Measures for Underground Facilities

Events	Resulting Measures for Underground Facilities
1964 Niigata Earthquake	<ul style="list-style-type: none"> <li>• Improvement of steel conduit joints</li> </ul>
1968 Tokachi-oki Earthquake	<ul style="list-style-type: none"> <li>• Laid underground cable into conduits</li> </ul>
1978 Miyagiken-oki Earthquake	<ul style="list-style-type: none"> <li>• Improvement of conduit joints (Duct Sleeve, Expansion Joint, Stopper Joint)</li> </ul>
1983 Nihonkai-chubu Earthquake	<ul style="list-style-type: none"> <li>• Apply steel conduits, stopper joints and gravel drain method in liquefiable ground</li> </ul>

#### 9.4 Response and Recovery Aspects

NTT set up the headquarters for the disaster at 8.30am on the morning of the earthquake, and began to check and restore. Switching units without backup power were revived by the end of the 18th of January (the second day) because vehicles with power generators were found. The 285,000 interrupted lines were decreased to 85,000 lines by January 19th. Checks for the tunnel containing communication cables in Kobe City was finished by January 18th. Restoration works were carried out by 1,000 workers of Kobe branch and 3,000 workers from other branches. 11 vehicles with power generators and 6 vehicles with satellite communications were utilised. On January 31st the restoration was finally over except for 38,000 lines which were impossible to restore due to building damage or collapse. Figure 2.4 shows the relationship between the recovery of telecommunications with those of the other key utility services.

To help handle the load, NTT added 5,000 lines serving the call district of Hyogo prefecture, which includes Kobe and several adjacent towns. The carrier also used selective call blocking to control call volume. Congestion due to the high number of inward calls restricted the availability of outward lines in the days following the earthquake, particularly for the cellular network.

In the days following the quake, NTT added more reserve circuits and installed telephone sets in the high-damage areas. They also installed approximately 2,700 devices, including 350 fax machines, at 760 locations around the city for free use by emergency officials and the general public. It also deployed temporary and portable communications systems throughout the region to support the rescue and emergency efforts, including vehicle-based satellite terminals and cellular phone sets.

The carrier adopted a triage approach in its repair operation, giving first attention to the relay stations and trunk circuits with the least amount of damage. On January 22, five days after the quake, NTT removed the selective call blocking from the network.

During the time that the NZNSEE reconnaissance team was in the area (i.e. the second week after the earthquake), the cellular phone system appeared to be functioning efficiently, despite cellular call volumes up to four times normal in the damage area (20-25% higher over the whole Kansai area). However the demand for rental cellular phones considerably outstripped the supply, making it very difficult to find a phone available for hire.

NTT has acknowledged that reliance on its sheer strength of resources was not enough to address the extent of problems that arose after the Kobe earthquake. The carrier is now involved in several initiatives aimed at improving the resilience of its network.

NTT's network planners have re-evaluated some of the carrier's deployment practices, and changes in thinking will be reflected in the way the carrier rebuilds its network in Kobe.

NTT has said that it will place a high priority on installing underground cabling and switching facilities in the rebuilding process. The reason for this is that above ground facilities incurred severe secondary damage from fires, floods, and debris from collapsed structures following the quake. Underground deployment is significantly more expensive than above ground facilities, but NTT believe the improved reliability and network integrity justify the expense.

In rebuilding the Kobe infrastructure, NTT will enclose underground equipment in specially hardened structures that are able to withstand greater levels of shock than conventional structures can sustain. NTT says it will develop a model transmission facility entirely underground in one of the restoration areas to demonstrate its new approach. In the Kobe and Kansai districts that suffered the greatest damage, NTT intends to provide all commercial users of network services with local-loop fibre installed underground.

One of the cellular network providers managed to increase the number of channels at three cell sites by 50% within a week and during February did the same to another 13 base stations. This action required the prompt co-operation of Japan's PTT Ministry.

#### 9.5 Interdependence Issues

The greatest dependency of the telecommunications networks is on power supply, and so their performance was greatly assisted by the rapid recovery of the power supply. Conversely, many of the other utilities were heavily dependent upon the main telecommunications networks. It is therefore somewhat ironic that one of the reasons given for the good performance of the power company is an independent communications system.

Four vehicles with satellite units were dispatched by NTT immediately after the earthquake but they could not reach their destination until the following day due to road congestion.

Several dedicated emergency communication circuits did not fare well. This included the failure of two dedicated NTT circuits used for automatically transmitting seismograph readings. As a result, there was a delay of over half an hour before the seismograph recording from Kobe was transmitted (manually, by wireless) to the Osaka District Meteorological Observatory. Until then, the peak shaking intensity was thought to be only JMA 5 (MM VII), which is below the threshold for severe damage to buildings. The Hyogo Prefectural Government's NZ\$125 million emergency satellite communications network also failed, cutting communications with central government and local municipal offices, as well as with the local emergency services. The systems stand-by generator was damaged during the earthquake, and although the back-up batteries worked, they lasted only two and a half hours.

JR West's communication system was another important emergency circuit that failed. Train crews normally communicate by radio with the stations, which are linked to head office by copper wire and fibre optic cables. All cables were severed by the earthquake and as a result, head office was unable to communicate with either the stations or any of the nine trains operating in the area at the time of the earthquake. Station staff took their own initiative and manually shifted signals to red immediately after the earthquake. Head office had attempted unsuccessfully to order the trains to halt.

## 9.6 Lessons for New Zealand

- Network management controls were important in maximising the network availability in the disaster area.
- Availability of portable engine alternator sets is important in a major earthquake.
- Overhead lines and cables can be a weak link.
- Emergency plans must allow for the management of large numbers of staff and contractors from outside the damage area.
- Mitigation measures employed by NTT in the design and installation of duct lines in liquefaction areas proved successful.
- Cellular Network providers need portable cell sites.

## 10 THE POLITICAL RESPONSE

### 10.1 General

This section of the report considers the reactions and responses of politicians to the Great Hanshin earthquake. A number of associated issues such as the management of overseas aid and resources is also commented on. Whilst in the time available only one meeting with a senior councillor of the Kobe City Assembly could be arranged, a wealth of valuable information was obtained from that source and other people met in the Mayor's Office of Kobe City Council.

### 10.2 Meeting With the Chairman of the Water Supply Sub-Committee of the Kobe City Council

A formal meeting was held between members of the Lifelines Study Tour and Councillor Kenzo Tanaka, Chairman of the Water Supply Sub-Committee. Mr Kanemitsu from the Mayor's

Office was also present, along with other City officials.

On behalf of the group, Wellington Regional Councillor Ernie Gates expressed New Zealand's sadness and condolences to the people of Kobe. Councillor Tanaka acknowledged with heartfelt appreciation the support offered by New Zealand in the form of blankets, clothes and other kindnesses.

Councillor Tanaka reviewed the events following the earthquake from the council's perspective, and made available information relating to the response of the City, Prefecture and National Government that is reported on subsequently in this section.

In his closing remarks, Councillor Tanaka stated the determination of the City of Kobe to build the city not only strong against natural disasters but also an affluent and comfortable city suitable for the 21st century. He expressed the wish that the co-operation between New Zealand and Kobe will further develop in terms of the study of protection against natural disasters.

### 10.3 Local, Regional and National Governing Structures in Japan

The Kobe City Assembly is the political body which makes decisions on significant policies affecting the city. This assembly has a total of 72 elected councillors. The municipality headed by the elected mayor administers the Kobe City Council.

The prefectural system operates at a regional level, with there being 47 prefectures in Japan. Kobe falls within the South Hyogo Prefecture, along with more than 100 cities and towns. The prefectures appear to act largely in a regulatory and monitoring role, and the prefectures contain sub-offices of government departments.

Kobe is however one of twelve Designated Cities (based on size), which means that it has full control over regional functions in the city, and so is largely autonomous with respect to the prefectural government. The South Hyogo Prefecture has a greater role in the areas outside Kobe City.

The National Government is the equivalent of our Parliament, although it features an Upper House (called the Diet).

Approximately 70% of the tax revenue from Kobe citizens goes to the national treasury.

### 10.4 The Response of the City Assembly and the National Government Following the Earthquake

#### *Kobe City Assembly*

By 5 pm on the day of the earthquake, 25 of the 72 councillors were able to come to an emergency meeting at the City Hall. The Mayor and Deputy Mayor reported on the immediate effects of the earthquake to these councillors. It should be noted that at this stage (ie. 12 hours after the event), it was thought that less than 1000 people had lost their lives.

For the week after the earthquake, councillors and city officials were principally occupied with organising the delivery of water and food to the homeless.

On 23 January the City Council established an *Emergency Management Committee* to address issues arising from the earthquake. Emergency Management Headquarters were

established by city officials, and the individual councillors were encouraged to send suggestions regarding disaster management measures to this single office.

The City Assembly gave priority to securing financial resources for restoration, with particular emphasis being placed on seeking assistance from the National Government. The Vice Chairman and other members of the Emergency Management Committee went to Tokyo nine times in the period February to April to meet the Prime Minister, other ministers concerned and members of the Upper House.

The results of these appeals include national assistance schemes for restoring the Port and related industries, the underground railway and the private railway, and the allocation of state funds for the disposal of disaster waste.

The following statement was included in a resolution of the City Assembly passed on 15 February 1995:

*"The people of Kobe recovered from war damage and the Hanshin Flood Disaster in the past. This is yet another occasion for the effort, perseverance and courage of the people of Kobe to prevail. This is the time of trial when an international disaster-proof city should rise out of the ashes under the banner of the people's city. The Kobe City Assembly pledges itself to make every effort to restore our city back to its full vigour, to the city of every citizen's dream".*

A Supplementary Budget was passed at the end of March, which modified the original 1995/96 budget. As a part of the measures contained in this supplementary budget, the remuneration allowance for City Councillors was cut by 10%. Another political consequence of the earthquake is that the election for city councillors, which was to be held in March, was deferred for three months.

Housing is the most immediate challenge for the City, and the biggest. The City is planning for 82,000 new houses to be built in the next three years, both by the public and private sectors.

#### **South Hyogo Prefecture**

The South Hyogo Prefecture established its own Earthquake Emergency Management Headquarters on 19 January.

We did not meet with prefectural officials, and so were not able to ascertain other specific actions undertaken and political inputs/ decisions made by the prefectural government with regard to the post-earthquake period.

Grants of approximately NZ\$1,500 were made by the Prefecture to those whose houses were partly or completely destroyed.

#### **National Government**

The National Emergency Management Headquarters was established in Kobe on 22 January. At a national level, the key decisions made included:

- Allocation of NZ\$1.5 billion out of the 1994/ 95 Budget Reserve for Disaster Restoration was made on 24 January.
- Decisions on the full coverage of the demolition cost of destroyed houses and the provision of 60,000 temporary houses for victims by the end of March were made on

January 28 and 29 respectively (ie. 11 and 12 days after the event).

- A Government ordinance on the application of the "Temporary management of leased lands/ housing in a disaster-stricken city" law was enacted on 6 February. It is understood that this ordinance gave the City of Kobe the authority to place a hold on reconstruction over severely damaged parts of the city pending a full planning review. This review was a zero-based planning process which took into account the possible widening of streets to reduce fire hazard and introduction of parks for improved amenity. In order to provide enough housing, taller buildings than previously permitted were required.
- An advisory body to the Prime Minister, "The Hanshin Awaji Restoration Council", was created on 15 February, with a one year term of operation.
- Legislation for local tax cuts for victims of the earthquake was passed on 17 February (ie. one month after the earthquake).
- On 28 February, NZ\$2.2 billion for building temporary accommodation and NZ\$0.5 billion for the disposal of disaster waste was made available. A law for special measures concerning employment creation in public work for disaster victims in the earthquake stricken area was passed, and land tax was halved for the Kobe area.
- On 3 March, food expense allowances at emergency shelters was raised from NZ\$13 to NZ\$18.
- On 24 March, a decision was made by the Ministry of Construction to aid repairs of private housing from public funding (*no details available*).

It was clear that both the Kobe City Assembly and National Governments faced difficult decisions in the days and months following the earthquake. Given the unexpected scale of the disaster, the Kobe City Assembly appears to have moved rapidly to set up appropriate structures. While the National Government was subject to some criticism for what was perceived as being a slow response, it appears that key mechanisms were made in a relatively timely fashion, given the nature of the central government processes.

It is interesting to consider the reaction and response of local and central government in New Zealand if such an event were to strike "next week". The painful process that the Japanese authorities have been through provides a clear view of the fundamental planning steps that should be undertaken in New Zealand before a major earthquake strikes.

#### **10.5 Associated Issues**

##### **Impact Assessment**

Assessing the impact of the disaster was the major problem encountered by all levels of government. A reasonable indication of the number of deaths took until the end of the second day to emerge. Major trouble spots were not easily identified.

This contributed to delays in response actions, and a lag in requests for assistance being made.

### *The Management of Foreign Aid*

City officials highlighted the practical difficulties associated with managing aid received from outside the region. Politicians and officials alike received criticism for rejecting some offers of foreign aid. Clearly there is a need for New Zealand to be prepared at the Central Government level so that the benefits of foreign aid is maximised.

As an example, overseas search and rescue teams created a number of difficulties for local officials. They did not speak Japanese, and required food, water and accommodation at a time when these were at a premium for all and there were sub-zero temperatures. They were also not familiar with the types of domestic construction (given that houses were where most people that could potentially be saved were trapped in). The real need was for Japanese helpers.

For physical assistance, the needs changed daily and at a rate faster than aid from overseas could respond to. On the first day, blankets were needed; on the second, water; and on the third, food. However, blankets arrived on the third day, water on the fourth and food on the fifth. This problem was added to by the difficulties due to transportation congestion in firstly unloading the material and getting it to a central warehouse when received, and secondly distributing it to the community centres.

### *Planning For Reconstruction*

Planning for reconstruction covers a wide area of issues. Key areas where difficulties can arise that have been highlighted by the Kobe earthquake include:

- Where to dispose of demolition material and associated debris
  - *the need in New Zealand to pre-plan and have the appropriate approvals under the Resource Management Act*
- Planning controls for reconstruction in areas of widespread destruction
  - *the imposition of a reconstruction moratorium in such areas is a logical reaction, but has created considerable anguish and dislocation*
- The approvals process for major repairs and reconstruction

These are areas that can and should be addressed in New Zealand.

Kobe City produced an outline plan for the reconstruction process in March, and compiled a more detailed version in June. This plan is understood to include target time frames, including inputs from each lifeline organisation, and budget issues.

### *Social Issues*

The most prominent social issues directly resulting from the earthquake appeared to arise from the enforced relocation of people from damaged houses to temporary accommodation in other areas. This is commented on more in the Housing section.

Alcoholism is also an area for concern. People who have lost their home and job are turning to alcohol in increasing numbers.

## 10.6 Lessons For New Zealand

- Fundamental steps in the recovery process can and should be planned now, including:
  - considering the process of applying the Resource Management Act in a post-earthquake context.
  - defining design standards and establishing streamlined approval processes for the reconstruction work.
- The role of Government in the *response* and *recovery* phases requires urgent clarification. The interface between Government and private sector needs to be defined (e.g. what the Government *will* do and what it *will not* do); input from the private sector in terms of physical reconstruction should be maximised and planned for.
- The importance of people being self-reliant for *at least* three days (in both home and work situations) needs to be continually reinforced. Employers (particularly lifelines or related organisations with a significant post-earthquake role) need to consider how they will meet this requirement.
- The value of the Local Authority Protection Programme (LAPP) scheme and other similar schemes and Earthquake Commission cover. In the absence of household earthquake cover, a number of owners of destroyed houses with existing mortgages are in considerable financial difficulty.

## 11 ECONOMIC IMPLICATIONS

### 11.1 General

To date only limited information has been made available regarding the economic implications of the Great Hanshin earthquake. While estimates of direct costs have been obtained from most of the lifelines organisations, figures which illustrate the effect on other organisations, companies and the community are not readily available, and are likely to remain in the private domain. Broader economic effects are dependent upon the time to achieve full recovery, with periods of years rather than months being involved.

This section of the report is therefore limited in its scope, although it is hoped that additional information in this area will become available with time. In this section, estimates for the direct costs to lifelines organisations current at the end of August 1995 are collectively summarised, leading economic indicators which compare the years prior to the earthquake to the six months following are presented and general observations are made regarding funding mechanisms implemented following the earthquake.

A case study of the effect of the earthquake on a major hotel is also included.

### 11.2 Summary of Costs to Lifelines

The estimates of repair costs to the various lifelines that were presented in the previous individual sections are summarised in Table 11.1.

These figures should be regarded as approximations only, given the number of organisations involved in some of the utility classifications. For example, the value given for roads is understood to include only those roads operated by the Hanshin Public Expressway Corporation. In some cases it is also

**Table 11.1 Summary of Costs Incurred by Lifelines Organisations**

Utility	Repair Costs	
	NZ\$ million	% of system replacement value
Water Supply	500	6%
Wastewater	670	8%
Electricity	3800	n/a
Gas	2900	9.5%
Telecommunications	460	n/a
Road (HEPC)	4300	n/a
Rail	3630	n/a
Port	10000	n/a
<i>Total</i>	26260	

difficult to separate estimates of repair costs from indications of costs for upgrading systems to current standards (damaged and undamaged components).

This table indicates that a total repair cost to lifelines organisations of the order of NZ\$26 billion has resulted from this earthquake. In addition, the electricity and gas networks sustained NZ\$125 million and NZ\$280 million loss of revenue. Where identifiable, the direct damage expressed as an average percentage of the estimated replacement cost of the lifelines networks lies in the range 6% to 9.5%. The damage ratio for the port is however likely to be considerably higher, and their damage cost estimate of NZ\$10 billion clearly has a significant influence on the total.

Recent work by Hopkins for the *Wellington After the Quake* conference (Hopkins, 1995a) indicated potential losses for lifelines in the Wellington metropolitan area in a Wellington Fault event to be approximately \$1 billion, which reflects an overall damage ratio across all lifelines organisations of 10.2%. An explanation for this figure being higher than those sustained in Kobe is that a higher proportion of the total value of key lifelines assets in Wellington lie within the predicted peak MM IX and MMX isoseismals.

Damage ratios from Kobe confirm post-earthquake observations that a significant proportion of lifelines assets can be expected to be undamaged. However this level of damage corresponds to a high level of disruption, and this is the aspect which determines the extent of economic loss sustained by the community at large.

### 11.3 Key Economic Indicators

Useful economic performance indicators have been obtained for Kobe City. These cover the both the pre-earthquake period and the post-earthquake months through until early and mid-1995.

They are presented in Table 11.2, with the figures for *Sales Volumes*, *Numbers of People Receiving Unemployment Benefit*, and *Exports and Imports* plotted in Figures 11.1 to 11.3.

It is understood that most of these economic indicators continued to improve in July, August and September, particularly as the Port raised its available capacity.

Key observations from these figures include:

- Monthly sales volumes in department stores fell to almost zero in February, rising again to almost half of the base figure (non-holiday and non-Christmas seasons) by the third, fourth and fifth month after the earthquake (Figure 11.1).
- The number receiving the unemployment benefit doubled within two months of the earthquake, and stayed at this level in the subsequent two months (Figure 11.2).
- Exports fell to one-third of pre-earthquake levels before picking up slightly in May (Figure 11.3) as the port returned to half its usual level of function. It is interesting to note that imports fell by a similar degree, and remained below exports. It can reasonably be conjectured that this situation would not exist for New Zealand where there is likely to be a greater dependency upon imports for many aspects of reconstruction.
- The industrial productivity index rose 10% above pre-earthquake levels in March, presumably as a function of reconstruction activity.
- In the five months following the earthquake, the Consumer Price Index has not risen above pre-earthquake levels.
- The number of bankruptcies fell below the pre-earthquake base level.

These trends have significant implications when viewed from a New Zealand context, noting some of the more favourable economic influences applying to Kobe and Japan. They provide a clear indication of the overall impact of an earthquake beyond the physical damage to people, buildings, bridges and services.

### 11.4 Observations Regarding Funding Mechanisms

#### *Funding Mechanisms for Utility Organisations*

Typical arrangements involved the National Government meeting demolition costs and also paying up to 80% of repair/reinstatement costs. A defined period applies for this arrangement, depending on the utility organisation concerned (e.g. 1 year for Hanshin Public Expressway Corporation, 2 years for Kobe City Sewage Bureau and 3 years for Kobe City Waterworks).

Strengthening or upgrading works that are now considered necessary after the earthquake are to be met by individual utilities. In a number of cases the separation or distinction between *repair* and *strengthening* work is difficult to define.

#### *Assistance for Private Organisations*

The Government agreed at an early stage to meet virtually all of the demolition costs incurred by residential, commercial and industrial owners of small or medium size buildings. This

Table 11.2: Summary of Key Economic Indicators For Kobe City  
(Pre - and Post - Earthquake)

	Industrial Productivity Index	Personal Consumption			No. receiving unemployment benefit	No. of bankruptcies	Trade Volumes	
		Average (thousand yen)	CPI	Sales Vol.** (million yen)			Exports (million yen)	Imports (million yen)
*1993	90	318	106.9	21327	11007	28	3892	2027
Apr-94	87	260	106.7	20220	10317	37	3881	2014
May-94	82	284	107.0	20401	10408	31	3286	1913
Jun-94	88	303	106.8	19242	11426	27	4160	1945
Jul-94	86	328	106.5	30821	11271	21	3848	1865
Aug-94	84	372	107.0	16207	12218	21	3754	2182
Sep-94	94	302	107.2	17118	11649	26	4127	2226
Oct-94	88	319	107.8	20172	11414	20	3978	2270
Nov-94	95	343	107.5	20978	11326	25	3919	2154
Dec-94	94	445	107.2	35317	10723	41	4396	2015
Jan-95	73	246	107.2	10157	9199	13	1582	1174
Feb-95	83	243	106.0	1455	15438	20	738	406
Mar-95	103	415	104.8	3776	23298	17	1477	420
Apr-95	90		105.5	9189	27339	21	1471	586
May-95			106.3	10810	26261	9	1824	849
Jun-95			106.6	10820		14		

\* monthly average

\*\* from 5 main department stores

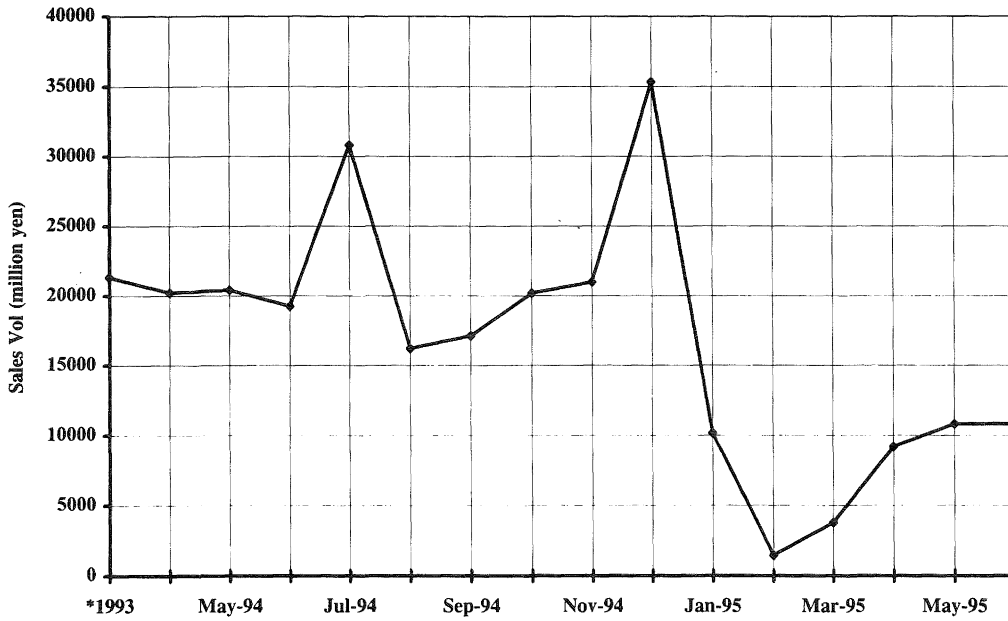


FIGURE 11.1 Monthly Sales Volumes (5 Main Department Stores in Kobe)

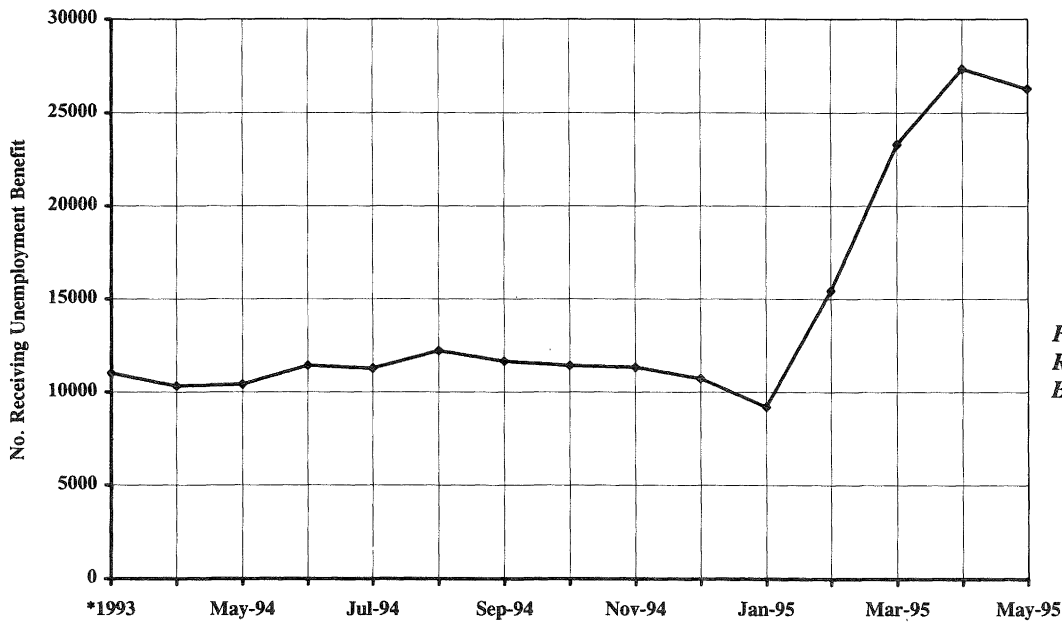


FIGURE 11.2 Number Receiving Unemployment Benefit in Kobe

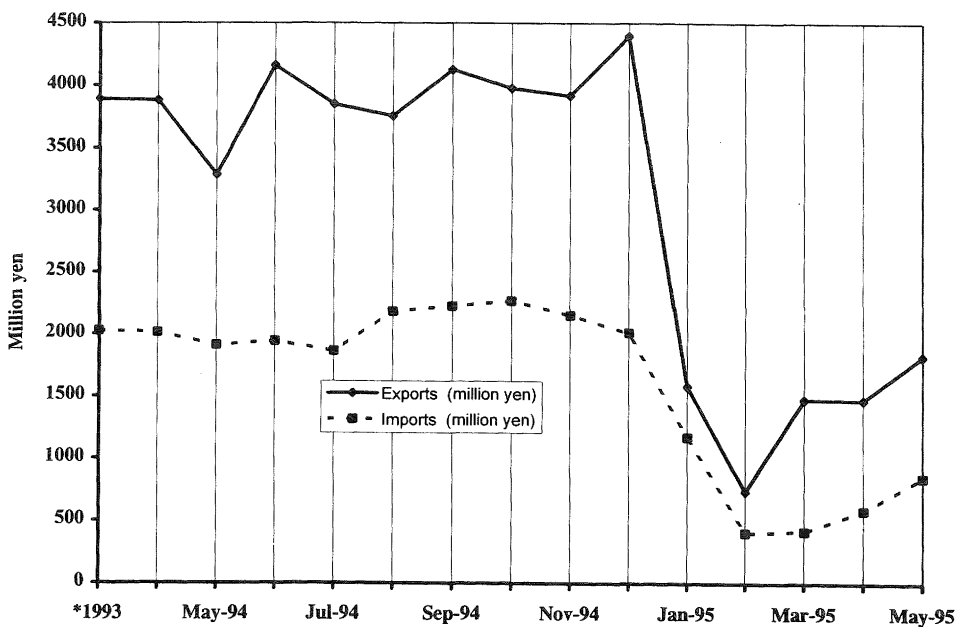


FIGURE 11.3 Monthly Trade Volumes For Kobe (Imports and Exports)

proved necessary due to the low level of insurance cover in Japan, and provided a significant 'kick-start' to the recovery process.

The issue of monitoring these costs is however arising as demolition proceeds and the total cost mounts, particularly with regard to commercial buildings and facilities. It is understood that payment for demolition for large buildings was based on unit rates, and some disputes are arising.

#### *Employment Insurance Scheme*

The immediate adverse effect of the earthquake in terms of unemployment and pressures on businesses led to the Government instituting an employment insurance scheme which will continue until the anniversary of the earthquake.

While details of the scheme have not been obtained, the objective is to help private companies affected by the earthquake to keep staff that they would otherwise be forced to make redundant during the recovery phase.

It is aimed at businesses that are likely to be able to continue, rather than propping up those are likely to fail. A general observation was made that up to 20% of businesses (of all sizes) could fail as a direct consequence of the earthquake.

There is speculation as to what will happen to unemployment figures following the expiry of this scheme in January 1996. The general view is that if the recovery of the economy as a whole continues at the current rate, the people that this scheme is designed to protect will be kept on in their jobs.

#### *Miscellaneous Observations*

A number of key industries were badly affected by the earthquake, including the Kobe Steel company which was forced to close for 4 months.

Approximately 80% of small shoe-making enterprises in Kobe are also believed to have been affected. These were concentrated in Nagata Ward, which was badly hit by fire. A number of these were effectively cottage industries located in older houses, and the combination of earthquake damage and the presence of solvents is understood to have greatly exacerbated the effects of the fire in this area.

One of the number of Japanese banks that collapsed in the third quarter of 1995 placed some of the blame for its situation on the Hanshin earthquake.

By September 1995, tourism was down by 50% on the figures for previous years (on a monthly basis). This is reflected in average hotel occupancy rates of 30% rather than the customary 60% at that time of year.

#### **11.5 Case Study: A Major Hotel**

Information relating to the effect of the earthquake on a 770 room hotel was obtained, and is presented as an illustrative case study.

The multi-storey building is situated on one of the man-made islands. It was designed in 1981, and sustained negligible structural damage. There were no injuries sustained in the hotel.

The surrounding ground settled up to 600 mm around the piled structure. It was interesting to note that the outside of the walls of building were detailed for some settlement by being tiled for approximately one metre below ground level.

There was a reasonable level of damage to fixtures and finishes, particularly to the upper level guest rooms. Most rooms needed some repair, which proved to be a messy exercise taking four months to complete. Contents damage included the loss of china in the hotel restaurants, with more than 200 television sets requiring replacement.

The immediate effect of the earthquake was a loss of power. Standby generators provided restricted power until mains power was restored at 10 am. Water and gas supplies were also cut, and a period of two weeks was taken to fix and restore these services. The hotel had big water tanks on the roof and at basement level for immediate drinking purposes until water trucks served the area. Bucketed water from swimming pools and fountains was used for toilet water in the days following the earthquake.

The hotel lifts were back in action (i.e. inspected and reset) on the same day.

Repairs costs were of the order of NZ\$8 million, which reflected a damage ratio of approximately 2%. While this is not a high level of damage, it is still a significant cost for a facility that effectively did not sustain any structural damage. The hotel was not insured.

The hotel was affected by the closure of the Port Island bridge to other than bicycles for 2 months. In the days and weeks after the earthquake, the hotel accommodated broadcasting company staff and gas company staff doing repairs to their networks. There was a peak occupancy level during this time of 300 (including staff who stayed 2-3 nights at the hotel, as they could not get easy access during this time).

The hotel re-opened on a limited basis within one month. By August, room occupancy was at 40% of the usual level, with bookings at 60% to 70% of the usual level for September. Significant factors in the time for the recovery of this hotel were firstly the fall-off in conferences and tourists in Kobe in the months following the earthquake, and secondly the difficulty in access to the hotel compared to others in the centre of the city itself.

## **12 TEMPORARY HOUSING**

### **12.1 The Scope of Temporary Accommodation Required**

The earthquake and subsequent fires led to the destruction of 60,000 to 70,000 houses in Kobe City. An estimated 40,000 to 50,000 houses were half destroyed. There was a maximum number of homeless of approximately 235,000 in Kobe City and 300,000 for the affected region as a whole.

The city is planning to build 82,000 new houses (both public and private) in three years, noting that the private houses will be privately funded.

A total of 235,443 people required temporary shelter immediately after the earthquake. It is understood that many of these people have subsequently moved in with relations in preference to temporary accommodation. Issues such as the

enforced relocation of affected people into camps many kilometres from their homes have arisen.

Approximately 40,000 temporary housing units have been constructed on 278 sites around Kobe. These sites are typically on reclaimed industrial land, with some parks also being used. These units were effectively provided by the City with funding from National Government. The average number of people per temporary unit is not known.

It is understood that a further 3-4,000 people would like to be in temporary housing, but are not prepared to live in the locations offered for reasons of business, schooling or being part of migrant communities (eg. Vietnamese). These people are either:

- (i) staying in tents
- (ii) staying with relations; or
- (iii) prematurely back in damaged houses

By September 1995 it was estimated that approximately 1,000 people were still living in tents.

In terms of overall progress, by the end of March, 30% of demolition and clean-up of houses was completed, whereas by the end August, 80% of demolition and clean-up of houses had been completed.

### 12.2 The Nature of Temporary Accommodation Provided

A brief visit was made to two temporary housing camps on Port Island. One camp had 460 units, the other 800, each unit of approximate size 5.5m x 3.0m. They were of insulated panel construction, apparently of good standard, although it was not possible to view inside. Washing machines and air conditioning units were on the outside (refer Figures 12.1 and 12.2).

The camps were provided with fully reticulated services, including new buried water and sewer mains. This level of deliberate preparation (i.e. not rushed immediately after the earthquake) was particularly impressive.

The wide cross-section of society occupying these camps was illustrated by the range of vehicles parked outside - there were some high quality cars in amongst more basic models.

The City of Kobe is looking at creating more temporary housing units, particularly in central areas where the people would like such accommodation to be. However there is no more unused land or park space available in the inner city area.

### 12.3 Issues Associated with Establishing and Operating Temporary Accommodation

The City seriously considered a cash payout to homeless people in lieu of arranging temporary accommodation. This was because (i) it suited some people better, and (ii) it would be cheaper for the city in long run (i.e. enable a maximum total payout ceiling to be established). However it was not legally possible to do this.

The City also considered increasing the quality of temporary houses, but this would heighten the problems of people not wanting to leave, particularly as it is rent free. People have been given up to one year to occupy the temporary units, but fears are growing about the likely difficulty in getting some people to leave in a year's time.

For the planning and costing of temporary housing, all associated costs need to be considered. These include:

- site establishment
- unit purchase, procurement and installation
- maintenance
- dis-establishment

There are concerns regarding the health of camp occupants, particularly through summer, as there are many elderly in the camps. The City is looking to establish a medical clinic at each camp in order to enable easy check-ups, and to keep critical eye on general health issues.

The City are encouraging the establishment of "camp councils" to report needs, etc. to council.

It is interesting to note the difficulties that would occur in a similar situation in New Zealand where people would not fit in well with a camp situation on even a short-term basis, due to aspects of societal behaviour being different from the Japanese.

### 12.4 Reconstruction Issues

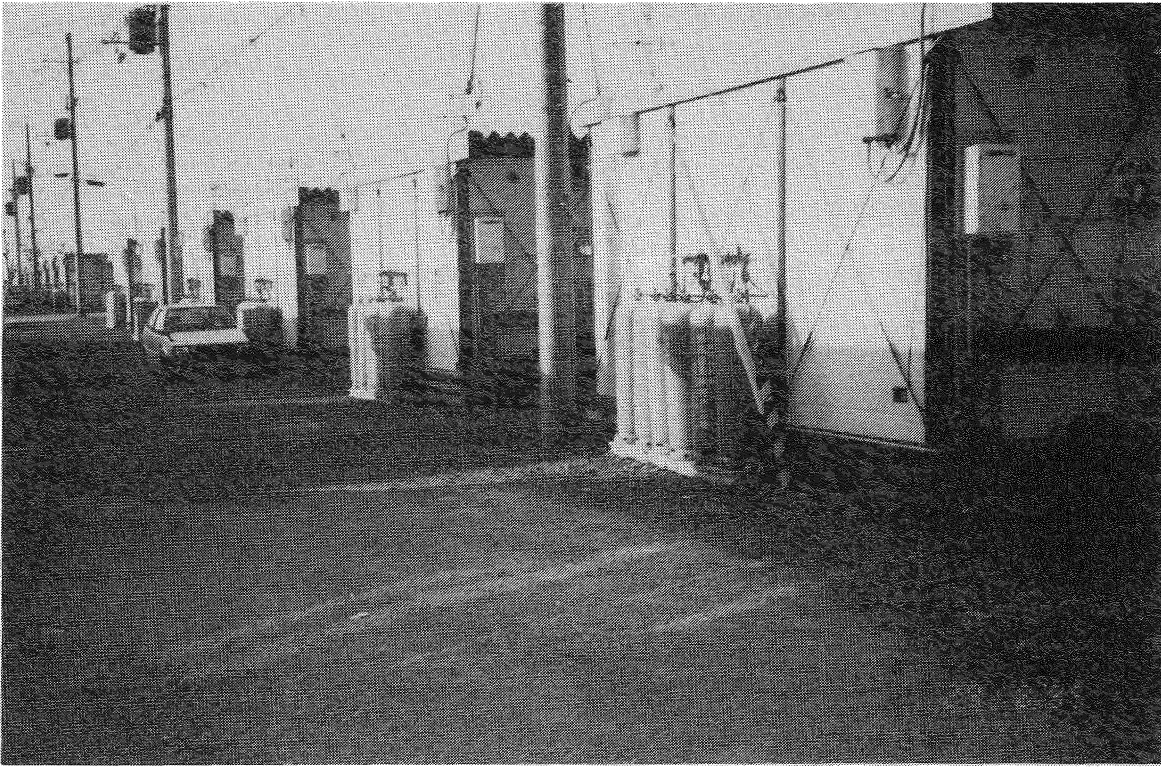
The Kobe Housing Phoenix Centre opened in a new building in August to act as information centre for those wanting to reconstruct houses from scratch. Some people however cannot reconstruct until planning issues in badly damaged and burned areas are resolved. Such issues include land surrender for wider roads, and the creation of park spaces.

This centre has offices for representation from major Japanese and overseas housing construction companies to discuss design and construction issues. Information on zoning status throughout the city is also displayed.

A model with recommended construction details, e.g. timber lining with ply lining and tie-down straps to foundations, is also on display.

### 12.5 Lessons for New Zealand

- The temporary and permanent re-housing of residents following a major earthquake requires considerable planning. All major metropolitan centres should establish plans for the procurement and establishment of temporary housing units, with particular consideration being given to the following points:
  - types and source of housing units
  - location, configuration and utility services requirements for camps
  - length of occupancy to plan these camps for
- It is considered that this planning should typically be undertaken on a regional basis, with primary input from emergency managers and planners. Input from lifelines managers should also be sought, e.g. proximity of housing camps to principal water supply mains; the infrastructural demands of establishing these camps should be factored into utility services response plans.
- Temporary housing camps should be planned to be as self-sufficient as possible, including the provision of medical services, etc.
- Re-location of people into camps some distance away from their homes is to a large extent unavoidable and can be expected to cause concern and resentment.



*FIGURE 12.1 Arrangement of Temporary Housing Units, Port Island*



*FIGURE 12.2 Temporary Housing Units Showing Services Reticulation*

- New Zealand housing stock is however expected to perform much better in terms of major damage than in Kobe.
- The provision of temporary accommodation for out-of-town workers assisting with post-earthquake reconstruction also needs to be considered.

### 13 EMERGENCY MANAGEMENT

#### 13.1 Taking Stock of the Disaster

Kobe's emergency managers were confronted with a number of problems they had not anticipated, and which hindered effective, timely, impact assessment from taking place. This was partly because a large-scale earthquake disaster had not been contemplated by the authorities. Although recent efforts had been made to prepare Kobe for typhoons and flood impacts, planning did not prepare either citizens or government for major earthquake. On top of this, Kobe's disaster plan was predicated on only part of the city being impacted, with the concomitant assumption that resources could be shifted internally. The numerous roadblocks of debris that obstructed emergency vehicles; the failure of the remote surveillance camera designed to provide areal views of the city; and overloaded telephone systems were apparently not completely factored into the city's contingencies.

Once fire, police and medical officers were able to extricate themselves from their houses and get to the nearest station they could reach, they faced the fact that many of buildings had also suffered damage. For example, six of the main police stations in Kobe had major structural damage. Three of the 11 fire stations in Kobe were damaged. Almost half the 1329 firefighters could not get to their stations within the first two hours, although 90% had reported in within five hours. Unlike some parts of eastern Japan where large earthquakes are expected and vital public buildings are reinforced, many of Kobe's critical facilities including emergency services were not.

Buildings that housed the Kobe Municipal Government and the Hyogo Prefecture Government were similarly affected. Located in the centre of Kobe, both sustained structural damage as well as substantial office disruption (files turned over, furniture toppled, and so on). Electricity supply and back-up generators failed. About 40% of Kobe Municipal Government's 20,000 employees were directly affected by the earthquake, and only 20% of the workforce was available for the first several hours. Under the City's disaster plan, all employees are obliged to report to their workplace and activate disaster planning procedures. The fact that they were unable to do so seriously impeded the city's initial actions. Moreover, since little consideration had been given to prioritising activity, staff reported to normal places of work and awaited further instructions.

Under the Disaster Countermeasures Basic Act 1961, city governments are required to establish a municipal headquarters for disaster countermeasures to execute emergency operations. The Mayor of Kobe, who also holds the position of Director, Kobe City Disaster Relief Headquarters, arrived at City Hall at 6.30am to find a skeleton staff attempting to initiate local coordination. The Vice-Governor of Hyogo Prefecture arrived at 6.45am. With the Mayor's presence, the City Government was able to set up its emergency operations by 7.00am. One of the first instructions the Mayor issued was to have an aide video what he could of the earthquake's damage. An early decision to deploy helicopters for the initial impact assessment was

confounded because the city's helipads were located on one of the artificial islands. On the way to the helipads, it was subsequently discovered that passage to the island was damaged, necessitating a two hour walk before the helicopters were accessed.

The 1961 Act also obligates prefectural governments to establish a disaster headquarters to collate disaster information from impacted municipalities in its jurisdiction and forward an assessment to Central Government, via the Disaster Prevention Bureau in the National Land Agency (DPB-NLA). This was not an easy task. The emergency radio telephone network of Hyogo Prefecture did not function because the controller computer was damaged, and normal telephone lines were congested. So, messengers were sent on foot to police headquarters and the fire command to obtain information. However, these attempts at information-gathering were stymied because officers became immediately engaged in rescue activities and could not report back. As a result, neither of the two services had an overall picture. The first damage estimate the Hyogo Prefectural Police Headquarters issued, at 9.20am, almost 3 hours after the earthquake struck, was '8 dead, more than 189 buried alive, 33 missing and 203 houses destroyed'.

At the national level, emergency response mechanisms start when an earthquake exceeding intensity V on the JMA (Japan Meteorological Agency) scale (i.e. MM VII) is reported. At 6.07am, the JMA informed DPB-NLA that a strong seismic event of intensity V had been observed at Kyoto. This was upgraded to intensity VI (9-10 MMI) at 6.21am, with the impact site re-located to Kobe. DPB-NLA called the National Police Agency (NPA) and the National Fire Defense Agency (NFA) for reports. However, little was passed on because local personnel had insufficient information themselves.

At 7.00am the public broadcasting corporation, NHK began showing footage of the affected areas. At 7.30am the DPB-NLA decided to convene a National Emergency Headquarters meeting. The Bureau continued to monitor the situation via television reports, and started to realise that the magnitude of the event was more serious than first thought. By 8.30am NPA alerted prefectural police headquarters of non-affected areas to be on stand-by; by 9.00am NFA did the same for fire commands.

By 9.05am the DPB-NLA was able to make telephone contact with a senior official of the Hyogo Prefecture, and urged them to send an immediate request to the National Self-Defense Forces (SDF, the Japanese armed forces). This was transmitted by the Governor of Hyogo at 10.00am.

All three levels of government have acknowledged that impact assessment was *the* major problem encountered. Not knowing what had happened, or where the major trouble spots were, became significant factors that resulted in consequential delays in response actions.

#### 13.2 Initial Co-ordination at Kobe

It was not until about 10.00am, more than four hours after the main impact, that officials in Kobe had a reasonable appreciation about what had happened. Given the scale of the disaster, this is not surprising. Together with the fact that co-ordination efforts and response priorities had to be established meant that early efforts were largely unco-ordinated. Police officers (agents of the prefectural government) were side-tracked into assisting initial rescue needs rather than undertake impact assessment and report-back. The Director of the USA-based

Disaster Research Centre (University of Delaware), who was attending a conference in Osaka at the time of the earthquake and was able to get to Kobe soon after, observed that during the early hours of the earthquake there was no apparent co-ordination at the 'street level' of public safety and response personnel. Moreover, there was no apparent attempt to control access to or movement within high hazard or severely damaged areas. She also reported that there was no evidence of an official system in place for inspecting damaged buildings or regulating entry into dangerous structures.

Mindful of the fire conflagrations following the Great Kanto earthquake of 1923, fire officers (a municipal government instrumentality that incorporates ambulance services) faced a similar dilemma as the police: should they give priority to fire-fighting or to search and rescue? Immediately after the main jolt, 30 fires broke out in the city. The need for search action was not great, because those who had escaped knew immediately where others were trapped. However, basic tools for rescue activity were in heavy demand. Many fire-fighters who set out to distinguish fires found themselves in the midst of such rescue activities. The failure of the water supply, and favourable wind conditions which prevented a rapid spread of fires helped ease the fire-fighters' predicament. It is worth noting that only 4.4% of the reported deaths were fire victims.

### 13.3 The Formal Organised Response

As soon as reliable information was available, the organised response was able to commence. It has been estimated that at the height of the remedy phase, over 60,000 fulltime professional responders and 30,000 volunteers were in the field. This number included 25,700 personnel from the Self Defense Force (SDF).

A little after 10.00am the NFA ordered fire reconnaissance helicopters outside Hyogo Prefecture to be dispatched to Kobe. At about the same time, the first police team from outside the area reached Awaji Island and immediately started rescue operations. At 10.15am SDF troops stationed 50 km away entered the city and commenced rescue actions. At about 10.15 the Japanese Red Cross had alerted its chapters in neighbouring prefectures, and medical teams started entering Kobe from 10.30am onward. Emergency hospitals surrounding Kobe sent teams in, and started on-site treatment. The Government of Japan established a Government Emergency Headquarters in Tokyo, and met for the first time at 11.25am. It decided on immediate priorities and confirmed the availability of resources. Soon after midday, a Minister left for Kobe by helicopter and was directed to report to the Prime Minister. An assessment team was also dispatched to the impact site to assist identify priorities and bottlenecks.

As part of its disaster planning, Kobe had entered into mutual aid agreements with nearby cities. These were mainly for specific resources, such as fire-fighters. As it turned out, however, these agreements could not be fulfilled because the resources specified in these contracts were desparately required where they were. Nevertheless, the call for assistance did not go unheeded. One thousand fire-fighters were brought in from outside the city on the first day; 2,700 on Day 2; 3,400 on Day 3; and over 3,500 on Day 4.

External assistance teams soon found a shortage of local resources. After shelter, the greatest demands were, in order, blankets, water, and food. When the blankets were distributed, and water/food provided, officials started calling upon the rest

of the nation to provide clothing, toiletries, powdered milk, and the like. While the Prefectural Government keeps a supply of blankets, food and water was difficult to procure immediately. The City Government had also set up agreements with local commercial enterprises to provide basic items such as food, clothing, blankets, and the like. But, many of these premises were severely affected by the earthquake and stock could not be accessed.

One of the biggest problems for the authorities turned out to be transportation. Roads and rail were severely disrupted. Congestion with the city was acute and severely hampered emergency response operations (a recent survey conducted in March by Kobe City officials into aspects of traffic behaviour during the earthquake indicated that people used private vehicles to evacuate as well as to check on friends and families (the latter because the telephone system was inoperable). The city tried to secure one major road for emergency access, but almost every route into the city had problems. Since road congestion had not been considered, it took almost a day to get signs printed that designated the priority route for emergency services.

Under the Disaster Relief Act 1948 evacuation camps must be established within seven days following a major disaster. Temporary housing (generally prefabricated designs) must be established within 20 days. These requirements were impossible to achieve, given the extent of the damage (unlike typhoon or flood damage, which the Act's sponsors had in mind). The city's disaster pre-planning included the identification of 364 pre-designated evacuation shelters, based on location, availability of open space and safety factors. Access routes, primarily for the evacuation of people had also been predetermined. As it turned out though, far more than this number of spontaneous shelters were created: at the height of demand, over 1100 shelters were established throughout the city. Even this number of shelters, however, did not prevent overcrowding, and sanitation became a problem in many. Many others camped in public parks or in make-shift shelters. A large number were taken in by relatives and friends, while others who had the means, moved away from the impact area. Those requiring emergency shelter reached a peak of 235,443 on the evening of the earthquake.

Problems with the amount and type of goods being donated were also reported. Newspaper articles reported a mismatch of supplies to the needs of the evacuees, citing a possible time-lag between asking for specific goods and the arrival of the donations. Large numbers of personnel, mainly volunteers, had to be deployed to deal with the vast amount of donated supplies. At times, the supply far exceeded the capability of personnel to distribute. This *cornucopia effect* is a well-known and researched disaster relief problem. The experience in Kobe, however, is one of the few occasions that it has been documented in Japan. Nevertheless, some concern was reported in various shelters at the lack of clothing and shoes, but generally relief supplies appeared to reach those in need. Criticism was also levelled at local government for failing initially to provide emergency aid to the elderly, people with disabilities, and others who fall through the net of conventional disaster relief measures, which tended to assume a uniform population, and hence similarity in victim needs.

The elderly living in shelters were particularly affected by illness due to living conditions and stress, with many unable to survive the conditions created by the disaster. Two weeks after the earthquake, reports of influenza and pneumonia, particularly among the elderly, were becoming common in some shelters.

Fortuitously, while the earthquake occurred in mid-winter, when temperatures are very cold and length of days are short, Japan's winter does not ordinarily coincide with high rainfall.

Although the city government provided information in a number of languages about available services and assistance, information for foreigners living in the Kansai area was found to be insufficient. Representatives from nine ethnic media agencies formed a relief group for foreigners immediately after the earthquake. They provided information about receiving aid and services and to provide moral support to minority groups in the devastated area. This information was distributed on air, via newsprint, and through the temporary shelters. The Hyogo Prefectural Police opened a 24-hour counselling service which could be accessed either by phone or in person at police headquarters in Kobe.

A special radio station (796 FM) was also established in Kobe to broadcast earthquake information to the public. This station was still operating two months after the event. Newspapers provided regular damage reports and provided a means of passing on any information useful for people affected by earthquake. This included information on counselling, medical aid, accommodation, easy loans, business support, job information, and relief supplies.

#### 13.4 Lessons for New Zealand Emergency Management

The Great Hanshin earthquake provides a number of significant and valuable response insights for the emergency management community, both for Wellington as well as for New Zealand as a whole. *Perhaps the key lesson for New Zealand is that disaster response is only as good as the effort and insights that go into pre-impact planning and preparedness.* Other key implications are highlighted below.

- Hazard analysis and risk assessment is an essential component of emergency response planning. The Kobe earthquake occurred in an area assumed to be free from major damaging tremors.
- Hazard mapping needs to include critical resource siting. Many of Kobe's key emergency response facilities, as well as many critical lifelines, were located in high-risk areas.
- Response planning must be based on realistic assumptions on what is likely to occur. Kobe's disaster planning was predicated on the assumption that only part of the city would be affected at any one time.
- Impact assessment is a critical factor in emergency response that has to take priority. Kobe underscores the need for a reliable impact assessment procedure. Because this was not built into their impact response programme, the allocation and direction of resources was confused and delayed.
- Impact consequence analysis should be a part of routine emergency management preparedness. In Kobe, emergency managers had little idea of areas likely to be damaged. Similarly, there was no assessment of likely downstream economic costs from damaging quakes.
- Disaster planning must be proactive and all-inclusive. In order to reduce uncertainty, the 'all-hazards' Comprehensive Emergency Management (CEM) model is a useful framework. Kobe's disaster plan was built around its 'pet hazards' of floods and typhoons. These agents have very different impact profiles from the earthquake that struck in January, 1995. Many of the post-impact difficulties the Kobe emergency management system experienced can be explained because Kobe appeared to have neither an all-hazards perspective nor a comprehensive approach.
- Ensuring that key emergency responders have a coordinated response plan is essential. The Integrated Emergency Management System (IEMS) is a practical and worthwhile approach to assist inter-agency pursuits during times of disaster. In Kobe, both horizontal and vertical integration was a problem.
- Outmoded legislation can hamper effective disaster response. It is important to review statutory requirements on a regular basis. All three key pieces of natural disaster legislation in Japan were outdated (Disaster Relief Act 1948; Disaster Countermeasures Basic Law Act 1961; Large-Scale Earthquake Countermeasures Act 1978). Similarly, introducing disaster-relevant legislation immediately following impact (Disaster Recovery Act 1995) does not produce good legislation.
- Disaster recovery planning must be seen as an integral part of preparedness and response planning. It is too late to start the process of recovery after an event has taken place.
- The need for Emergency Operations Centre (EOC) personnel to be selected and prepared, through regular training, for specific tasks was also underscored in the Kobe disaster. The earthquake raised questions such as how EOC personnel are to be alerted and how to ensure they can get to the EOC.
- Similarly, the Kobe experience raises issues such as securing communications systems between components of the wider emergency management system.

Two other points are worth raising in conclusion. First, the Japanese emergency management system is more reliant on *technical resources* than it is on *organisational development*. Hence, problems that arise have a tendency to be 'solved' by developing or introducing new technologies, rather than assessing the intra- or inter-organisational structures, systems or processes. The problem with this orientation is that, irrespective of the type, level, and quantity of technical and physical resources that are available, without a good management system they are unlikely to be put to their optimal use. Effective disaster management is, above all, good management applied to a specific circumstance.

An allied point is that, overall, Japan has sufficient rescue and medical personnel to respond to emergencies, as well as abundant supplies of consumer goods in the country. As such, the emergency management system is not reliant on in-kind assistance from external sources. However, almost all the international media and many international rescue groups fail to understand or appreciate this reality. Both these groups incorrectly believe that any disaster provokes internal mayhem to the point that outside assistance is imperative. As the Great Hanshin earthquake revealed, failure to 'comply' with disaster myths can produce widespread criticism, and force governments to accept assistance, even when it creates more problems than it solves.

While New Zealand does not enjoy the same level of resource availability as Japan does, it will nevertheless face a similar dilemma with reference to being faced with inappropriate, even unrealistic, offers of help. Even following a major urban earthquake disaster, it will not be a nation dependent on external aid, although many elements of the international media and rescue groups will think otherwise. The emergency management system, especially at central government level, needs to think seriously about how it is likely to respond to the *cornucopia effect* that will be part of the post-impact environment.

- the main expressway through Kobe will be partially re-opened in March 1996
- by the end of August 1995, the port was operating at 63% of the pre-earthquake activity level, and retail activity was 50% of that prior to the earthquake

This level of response and recovery has in the main been due to strong regional and national support from other utilities, and the availability of a massive contracting workforce and material supply.

There is however an incredible amount of work that still has to be done. Large scale reconstruction will continue for several years. Having reinstated the basic network service in the case of utilities or carried out temporary repairs for the bridges, permanent repairs are being undertaken. Added to this, however, is the need to plan and implement the upgrading of the systems to current standards in the light of the earthquake experience, and in many cases this is being undertaken concurrently.

It is clear that both the Kobe City Assembly, South Hyogo Prefecture and the National Government faced difficult decisions in the days and months following the earthquake. Each of these levels of government appear to have moved rapidly given the unexpected scale of the disaster to set up appropriate structures and implement funding mechanisms.

Key economic indicators for the City of Kobe for the months following the earthquake send clear warning signals for New Zealand in general, and Wellington in particular.

#### *Concluding Observations*

An over-riding impression from the visits by members of the New Zealand lifelines groups is the many parallels between Kobe and Wellington (e.g. geography (hills, limited flat land), geology and seismicity (ground liable to liquefaction, presence of faultlines), port facilities, etc.).

These parallels extend to the expected nature and range of damage in the Wellington Fault scenario as currently portrayed.

For Christchurch and other areas in New Zealand, the parallel with Kobe is that an earthquake of this scale was not anticipated, despite the national context of high seismicity and the presence of liquefaction-prone geological formations..

It is almost certain that the Kobe Earthquake will provide the strongest parallels for New Zealand of any earthquake this century. Continuing study of the impacts of this earthquake will have significant potential benefits for New Zealand organisations involved in earthquake risk reduction, and lifelines in particular. Additional valuable information from this event will continue to become available in English from Japan and elsewhere.

The degree of preparedness and mitigation measures undertaken by the Japanese was very impressive. This was partly due to their preparedness in relation to frequent typhoons. In the absence of a significant earthquake in a major city in New Zealand in recent years, the same level of preparedness cannot be assumed.

Impact assessment was the major problem encountered. Not knowing what had happened, or where the major trouble spots were, became significant factors that resulted in consequential delays in response actions.

## 14 SUMMARY AND RECOMMENDATIONS

### 14.1 Summary

#### *The Main Effects of the Earthquake on Kobe*

The main effects of the earthquake can be summarised as follows:

- More than 5,500 people were killed and 26,800 seriously injured. Approximately 300,000 people were made homeless
- Vital transportation routes and the port facilities were significantly disrupted
- Key utility services sustained considerable damage. The earthquake resulted in an estimated overall direct cost for repairing lifelines networks and facilities of approximately NZ\$26 billion
- Buildings and facilities designed and constructed prior to the first issue of the current design standards in 1981 sustained the greatest damage, but well designed and constructed structures performed well

#### *The Immediate Response of Lifelines Organisations*

While there was a considerable amount of confusion on the day of the earthquake, overall the immediate response was very effective. As a leading example, the Hanshin Expressway Public Corporation closed the complete network down within three minutes of the earthquake.

Impact assessment was the major problem encountered. Not knowing what had happened, or where the major trouble spots were, became significant factors that resulted in consequential delays in response actions.

The rapid mobilisation of key equipment items such as truck-mounted electricity generators (56) and water trucks (420) only serves to underscore a major vulnerability in New Zealand.

Co-ordination problems were encountered with some fires resulting from the restoration of power supply in areas where there was a buildup of gas present.

#### *The Recovery and Restoration Process*

The achievements since the earthquake are extremely impressive. In addition to the rapid restoration times outlined in this report for most utility services (Figure 1.4), these include:

- the rail system back in operation by June 1995

Of particular significance to New Zealand is that there will not be the large pool of skills and resources available as in Japan. This means that it is even more important that mitigation, preparedness and response planning in New Zealand is to the highest standard in order to minimise disruption and enable the quickest possible recovery after an earthquake.

There is a need for New Zealand cities to ensure that key structures within the transportation network are robust enough to survive a major earthquake event, to be able to quickly control traffic after the event, and to be able to restore traffic capacity.

The experience gained from the earthquake will be of considerable benefit to mitigation, response and recovery planning in New Zealand, particularly in Wellington which has direct geological and topographical parallels with Kobe.

#### 14.2 Key Lessons for New Zealand

- The fundamental importance of developing response plans, and the holding of annual exercises to familiarise people with the plans and their roles. This earthquake has again confirmed that lifelines organisations cannot anticipate a staff turnout of more than 50% on the day of the earthquake, and that this must be planned for.
- Fundamental steps in the recovery process can and should be planned now, including:
  - considering the process of applying the Resource Management Act in a post-earthquake context.
  - defining design standards and establishing streamlined approval processes for the reconstruction work.
- The painful process that the Japanese authorities have been through provides a clear view of the essential planning steps that should be undertaken at a political level in New Zealand before a major earthquake strikes.
- The role of Government in the *response* and *recovery* phases requires urgent clarification. The interface between Government and private sector needs to be defined (e.g. what the Government *will* do and what it *will not* do); input from the private sector in terms of physical reconstruction should be maximised. The issue of clarifying responsibilities assume greater importance in view of the recent splitting up of the assets of national and local government agencies.
- The criticality of transportation and access in the response and recovery phases. The ability to control and prioritise traffic in the days following an earthquake has a major impact on the response of utility operators. The unavailability of key road and rail routes has been the single biggest hindrance to the recovery process in Kobe.
- The importance of people being self-reliant for *at least* three days (in both home and work situations) needs to be continually reinforced. Employers (particularly lifelines or related organisations with a significant post-earthquake role) need to consider how they will meet this requirement.
- Networks, facilities and buildings constructed to modern standards can generally be expected to perform well.
- There is a need to urgently address the seismically vulnerable buildings and bridges designed and constructed

prior to the modern design standards of 1976. Such a move will require regulatory backing, which in turn will necessitate legislative change.

- Physical mitigation works undertaken by lifelines organisations have proven worthwhile in major earthquakes.
- Lifelines in areas prone to liquefaction and in soft, poorly compacted soils are highly vulnerable to earthquake damage.
- The value of the Local Authority Protection Programme (LAPP) scheme and Earthquake Commission cover in providing a base level of financial support for those eligible. In the absence of household earthquake cover, a number of owners of destroyed houses with existing mortgages are in considerable financial difficulty.

#### 14.3 Recommendations

##### *General Recommendations*

- The direction and emphases of the Wellington and Christchurch Lifelines Groups in terms of *co-ordinating hazard information and mitigation measures*, and *facilitating response planning* is appropriate, and should be strongly continued. The restoration of utility services in the days after an earthquake will have a major impact on the morale of a community, and planning to minimise this timeframe is a key objective.
- Central and Local Government agencies must develop plans which outline their response to a major earthquake. These plans should include provision for compiling a restoration strategy, including the scope of such a plan, at an early stage following the event. There is full support for the *Disaster Recovery Review* and its work in this area.
- There is support for the initiatives of the Building Industry Authority and the New Zealand National Society for Earthquake Engineering in addressing seismically vulnerable buildings designed and constructed prior to the modern design standards of 1976, and encouragement for this work to proceed with urgency.
- Lifelines organisations must place emphasis on ensuring the robustness of critical structures such as control facilities and record storage buildings.
- GIS systems and related methodologies for the analysis of lifelines systems need to be developed and used on a more widespread basis in New Zealand.

##### *Specific Recommendations*

- Councils in conjunction with Transit New Zealand should develop plans for traffic control immediately after earthquakes. Ensuring appropriately prioritised access to affected areas is extremely important.
- All response plans must include provisions for obtaining resources and materials. Such provisions should be *in addition to* mutual aid agreements, and must take into account the concurrent demands of other utilities.

- All utilities should review their post-earthquake communication arrangements, and consider backup mechanisms in the event of failure of the frontline system
- Utility organisations should make an annual commitment to response planning in terms of specific prior time allocation. It appears that despite best intentions, for many organisations this work is not being carried out due to the high level of everyday workloads resulting from reduced staff structures. There should be an associated commitment to participating in annual exercises to be organised on a regional basis to evaluate the effectiveness of response plans.
- A national schedule of key resources such as truck-mounted generators and temporary housing units should be compiled.

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**Editor's note:** Copies of the Wellington Earthquake Lifelines Group's 1995 Report, from which this paper was extracted, are available from the Wellington Earthquake Lifelines Group, P O Box 10-804, Wellington (Fax (04) 499 7254). This report includes colour illustrations and a description of the Group's other activities.